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# Laboratory Studies of the Hydraulic Performance of One-Story and Split-Level Residential Plumbing Systems With Reduced-Size Vents



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# Laboratory Studies of the Hydraulic Performance of One-Story and Split-Level Residential Plumbing Systems With Reduced-Size Vents

Building Science Series



Robert S. Wyly, Grover C. Sherlin,
and Robert W. Beausoliel

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## Foreword

Housing has concerned mankind throughout history, and continues to occupy the talents of people in many professions. This is certainly true at the National Bureau of Standards, where a tradition of housing research stretches unbroken from the early 1900's to the present. Today, the Center for Building Technology is involved with a broad range of housing problems. For example, an extensive series of experiments, using an advanced plumbing tower that provides great flexibility of operation, has shown that in many cases plumbing vents of reduced size perform quite well.

In these tests, drainage systems simulating those of one-story and split-level dwellings produced satisfactory performance with vents smaller than those specified by building codes. Use of reduced-size vents would help conserve copper and iron, and could reduce the plumbing costs of one-family units by $40 to $80. Such information will be useful to regulatory authorities when considering code changes, and should also be of interest to the plumbing engineering profession.

Richard W. Roberts
Director

# Contents

# Laboratory Studies of the Hydraulic Performance of One-Story and Split-Level Residential Plumbing Systems With Reduced-Size Vents*

**Robert S. Wyly, Grover C. Sherlin, and Robert W. Beausoliel**

A laboratory study of one-story and split-level experimental drainage systems where the vents in some cases were varied from one to six pipe-sizes smaller than those presently specified by codes showed satisfactory hydraulic and pneumatic performance under various loading conditions. The research was originally sponsored by the National Association of Home Builders and the National Bureau of Standards and more recently by a program of the Department of Defense through the Tri-Services Investigational Committee on Building Materials. This paper presents criteria recommended for the design and evaluation of systems using reduced-sized vents and a sizing table for one- and two-story systems. The laboratory work also contributed to the development of analytical and test procedures needed for evaluating the application of reduced-size venting to a broad range of innovative drain-waste-vent designs for buildings of any height.

This work indicates that, in some circumstances, reduced-size venting might be a good alternative to other types of drainage systems for multi-story buildings which use conventional or innovative venting concepts. Because this study involved only a limited number of drainage system designs, it is recommended that ongoing field and laboratory studies be explored if code changes are contemplated to permit the use of smaller vents.

Key words: Hydraulic criteria for plumbing; hydraulic test loads; plumbing-vent sizing; reduced-size vents; sanitary DWV systems; secondary ventilation; testing plumbing systems; vents for plumbing.

## 1. Introduction

### 1.1. Background

The work described in this paper was initiated under a Grant-in-Aid Program with support from the National Association of Home Builders (NAHB). The NAHB requested that the generally accepted criteria for venting be reexamined and proposed specifically that the hypothesis be tested that vent sizes may safely be reduced appreciably in size below those presently allowed by codes. Recommendations for the scope of and approach to the work were furnished by an eight-member technical advisory committee including representatives from Federal agencies having responsibility for housing construction and for health and safety, from the housing construction industry, and from the engineering profession.

The committee first reviewed relevant aspects of the fluid dynamics of plumbing systems such as those installed in one-story and split-level residences. Many problems were identified, but the recommendation was made that the research be restricted to problems for which meaningful laboratory measurements could be obtained with resources available to the program. and that study of other problems be deferred, e.g., those dealing with the development of fouling, scaling, or corrosion over a period of time under service conditions; those dealing with the performance of different piping materials or with the hydraulics of fixtures; or those concerned with water conservation.

### 1.2. Principal Objectives

The main objectives were to examine the hydraulic and pneumatic performance of selected sanitary DWV [1] systems utilizing vents smaller than generally allowed by codes, and from this information, to present recommended criteria for the guidance of plumbing system designers and regulatory authorities. In the process of achieving these objectives it was anticipated that progress would be made in the development of relevant performance criteria and of a methodology for testing plumbing systems.

### 1.3. Scope

The laboratory work consisted mainly of a considerable number of tests made on two test setups representing complete sanitary plumbing drainage systems. In addition, several important tests were made on simple "components." some of which were conducted on selected parts of the complete plumbing systems.

*A number of terms have been defined in section 7.1.

[1] Signifies "drain-waste-vent."

This paper describes in detail the venting tests on the two laboratory test setups representing complete DWV plumbing systems. One of these was patterned after the plans for a one-story, single-bath, slab-on-grade house, as specified for a housing project that had been constructed by one of the member companies of the NAHB. The other test setup was constructed from a plan for a three-level, two-stories and basement, three-bath house developed jointly by the project staff and a representative of NAHB, specifically for experimentation.

The work on simple components provided significant hydraulic and pneumatic functional performance data that helped explain the performance observed with the complete DWV systems. Three publications have been issued describing portions of the research on the complete systems and the components [1, 2, 3].[2]

### 1.4. Performance Criteria

The fundamental, qualitative performance requirements for sanitary DWV systems are that (1) the waste water must be conveyed to a public sewer or other acceptable point of disposal without nuisance or health hazard, and (2) the essential functional performance must not deteriorate too rapidly nor require excessive maintenance under a normal service environment. A more detailed breakdown of the requirements was presented in the National Plumbing Code [4]. Experience has shown that conformance to these requirements is facilitated for conventional gravity systems by consideration of the following general principles at the stages of design and evaluation.

a. A gas barrier (trap) should be used for each plumbing fixture to prevent passage of sewer gases or vermin into the house. A water-sealed trap with a seal depth of at least 2 inches has generally been found adequate; however, deeper trap seals may be desirable under some circumstances, e.g., they increase resistance to siphonage and afford extended protection against evaporation. Trap geometry and symmetry can substantially affect trap-seal response under dynamic loading. Other types of gas barriers would be necessary for drainage systems utilizing pressure or vacuum.

b. Pneumatic-pressure fluctuations (excursions) inside each fixture drain should be limited to a level that will prevent excessive depletion or disturbance of the trap seal and that will not cause annoying drainage noises. Traps-seal retention [3] of at least 1 inch or one half of the full trap seal, whichever is greater as determined by realistic test procedures, should be generally adequate. Rather than this, however, most plumbing codes actually require that acceptable designs provide for the maintenance of a pneumatic pressure range throughout the system of ±1 in of water column, under normal loads. Further, many codes proceed to specify the sizes, lengths, and configuration categories that are required. Thus, the designer is inhibited from proposing designs based on the trap-seal retention criterion, since such designs may conflict with code specifications on dimensions, configuration, or vent pressure excursion.

c. Peak hydrostatic and hydrodynamic pressures in the drainage piping should be limited to a level where waste water originating from other fixtures will not back up into any particular fixture or into its trap. Generally accepted practice tends to recognize this need and provides for the control of these pressures by sizing all nominally horizontal drains having two or more inputs so that they will flow significantly less than full (e.g., at ½ full depth) under design load conditions. Codes generally take this approach in prescribing sizes for horizontal fixture branches to which two or more fixtures are connected, as well as for primary and secondary branches of the building drain and for the building sewer. Thus, a designer is effectively inhibited from proposing a design in which a hydrostatic head above the drain would exist under design load conditions, even when the pipe line being considered (e.g., building drain or building sewer) would have no floor drain or fixture connections for many feet above its invert. Although pressure drainage in this sense was proposed in 1940 by a governmental committee on housing research [5], the idea has not been incorporated in codes.

It should be understood, however, that if the overall design depends on pressure or vacuum relief (venting action) through the air space over the water in a horizontal drain, the drain cannot be allowed to flow full. Thus, in considering full-pipe or pressure drainage in a gravity system utilizing water-sealed traps, it may be appropriate to consider trade-off values between drain and vent piping under some circumstances.

Of the several considerations listed above, trap-seal retention is usually considered to be of the greatest importance. In early investigations of stack venting, wet venting, self siphonage, and the hydraulics of plumbing fixtures and drainage stacks [6, 7, 8, 9] important determinations were made utilizing measures similar to the criteria discussed above. For example, the study on self siphonage [8] utilized trap-seal reduction as the principal measure of adequacy of performance, and the study on stack venting [6] recognized blow-back as one of the measures of performance of DWV systems.

In figure 1 the result of moderate vacuum or suction on trap seals is shown in illustration A-3 and the result of excessive suction is shown in A-5. These effects may be brought about by water flowing in other parts of the system (induced siphonage) or they may be caused by the action of water discharged from the fixture served by the trap being considered (self-siphonage). In this example, the suction is assumed to be relatively slowly applied and released. If a cyclic (fluctuating) suction is applied at a critical frequency, effects may be worsened due to rocking action, as explained below for back pressure.

[2] Figures in brackets indicate the literature references in sec. 6.
[3] Trap seal retention is that depth of water remaining in the trap after the trap has been affected by passage of fluid through the trap or by action of suction or back-pressure in the DWV system.

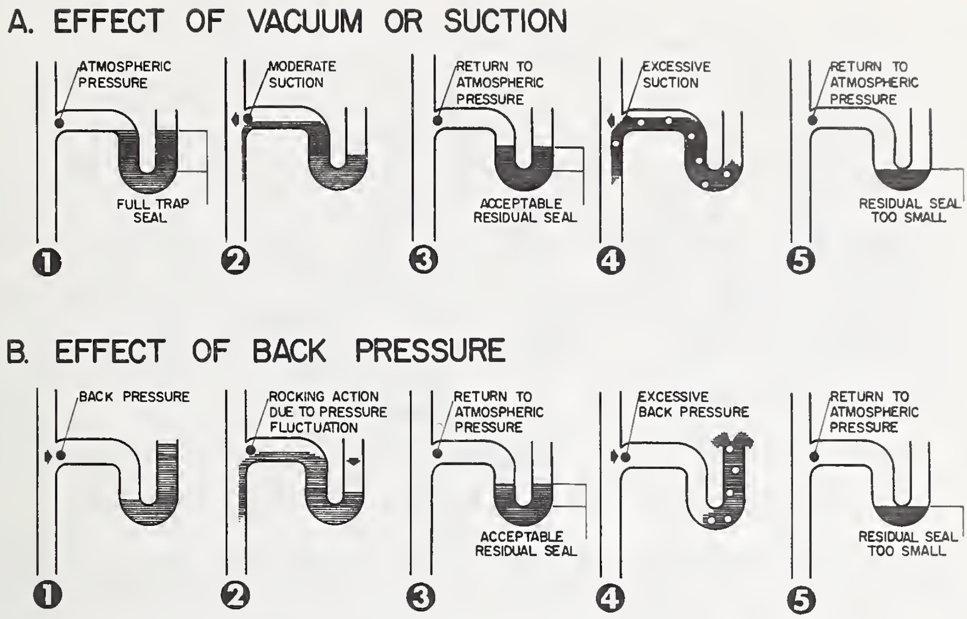


FIGURE 1. *Illustration of the effects of vacuum and back pressure on idle trap seals.*

Illustrations B-1 through B-3 show how a moderate positive (back) pressure fluctuation in a trap arm may cause fluid in the trap to first rise toward the fixture and upon a sudden release of the pressure create a rocking action in the trap that results in some loss of trap-seal fluid into the drainage stack. This rocking action may be particularly effective in reducing the trap seal of an idle trap subjected to pressures fluctuating at a frequency approximating the natural frequency of the trap seal. Excessive back pressure, shown in B-4, can eject sewage from the system into the fixture, or in extreme cases into a living area. Both the rocking action, and the ejection phenomenon sometimes associated with excessive back pressure, can result in excessive depletion of trap seal, as shown in B-5.

The criterion adopted for defining satisfactory trap-seal performance in this study was a trap-seal reduction not exceeding one inch. This would be equivalent to a trap-seal retention of 50 percent, in a trap having a full seal depth of two inches. Plumbing codes generally require that traps have seal depths of at least two inches, but limit greater seal depth in traps to four inches unless special approval is granted by the cognizant authorities.

The primary objectives of studying the two particular DWV systems described herein were (1) to obtain performance data that could serve as the basis for design procedures for sizing the dry vents of systems using the RSV [4] principle and (2) to develop experience in test-load selection, measurement techniques, and test procedures generally that could be utilized in the definition and standardization of a methodology for evaluating hydraulic and pneumatic performance of any DWV system.

Fixtures in the two systems were not varied as part of the study, but selected wet [5] and dry [6] portions of the DWV system were changed during the study. The lengths and diameters of the vents were varied, and with each variation some selections in fixture-discharge loadings were made. Under each set of conditions, measurements were made of trap-seal reductions, particularly for the trap seals of idle fixtures.

[4] Signifies "reduced-size venting."
[5] A "wet" pipe conveys waste water intermittently.
[6] A "dry" pipe carries air only.

## 2. Venting Studies Conducted on a Test Setup Representing a Complete DWV System for a One-Story, Single-Bath Slab-on-Grade House

### 2.1. Purpose and Scope

A DWV design for a one-story slab-on-grade house was selected for the initial studies for the sake of simplicity and because it was understood that at the time the study was undertaken, single-family-detached, slab-on-grade houses comprised the majority of living units under construction. The plumbing system included the five fixtures usually considered to be a desirable minimum, even for low-cost housing. By observation of the effects upon trap seals, caused by the introduction of selected hydraulic loads into the plumbing system, it was anticipated that a rating of satisfactory or of unsatisfactory operation of the system could be obtained. Test plans included measurements of air flow in vents, water depths and velocities

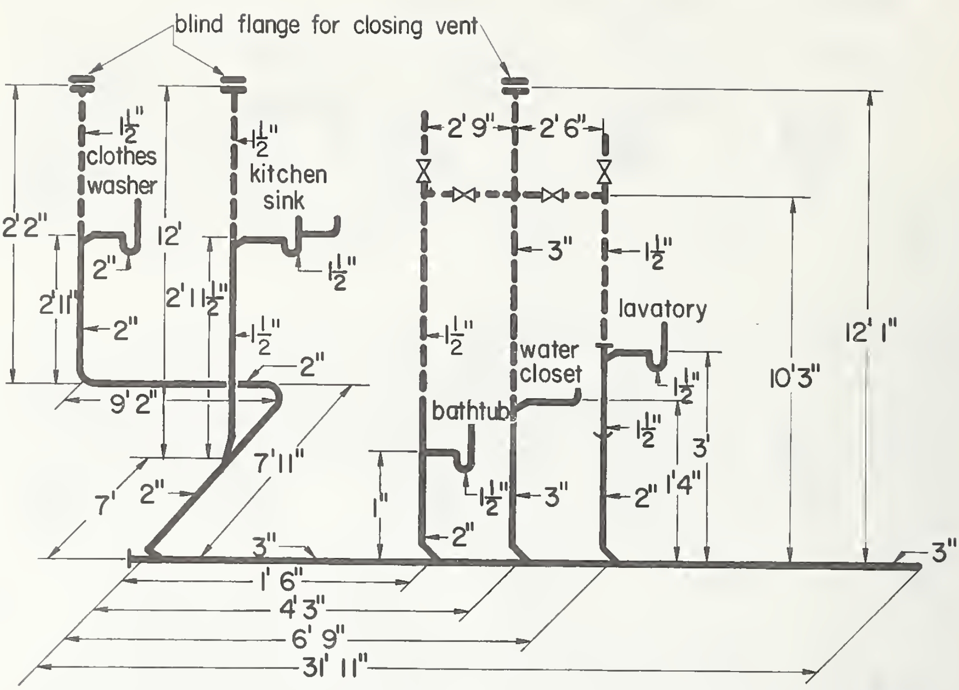


FIGURE 2. *One-story, slab-on-grade DWV test system, showing plumbing dimensions and means for closing selected vents.*

in drains, and air pressures in stacks or trap arms for possible correlation with the effects of the hydraulic loads on the trap seals.

As the study progressed, when test loads were applied to the system, modifications were made in the system piping as follows:

1. Vents and drains sized as shown on builder's plans, see figure 2.

    (a) All vents were open.

    (b) All vents were closed.[7]

    (c) All vents were open except for bathtub and lavatory.

    (d) One vent was open with four closed and two vents were open with three closed (15 variations).

2. The two-inch cast iron building-drain branch that served the clothes washer and kitchen-sink for the tests in (1) was replaced by a three-inch cast-iron drain, as indicated in figure 3.

    (a) All vents were closed.

    (b) One-half-inch inside diameter (i.d.) flexible plastic tubing vents, each 20 feet long, were connected to a 2-inch copper-tube manifold which was closed.

    (c) Same as (b) except that manifold was open to the atmosphere.

3. Same as (2) except final 14.7 feet of building drain was replaced with 3-inch transparent rigid acrylic plastic pipe.

    (a) One-half-inch tubing vents, each 20 feet long, were connected to a 2-inch manifold which was closed.

    (b) Same as (a) except manifold was open.

    (c) Individual vents were closed off 5 feet above floor level.

[7] By use of valves and blind flange plates (see fig. 2).

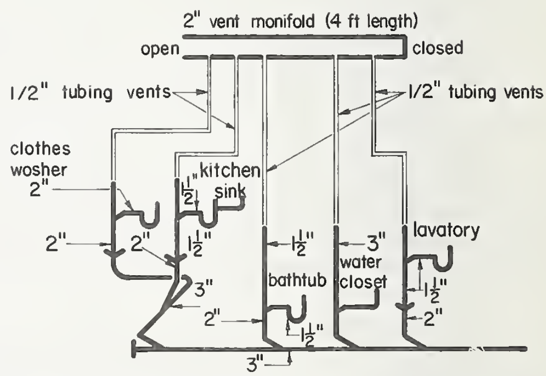


FIGURE 3. *Schematic representation of one-story, slab-on-grade DWV test system, showing reduced-size vents and manifold vent terminal.*

4. Same as 3(b) except the one-half-inch vents were successively 50 feet, 40 feet, 25 feet, 10 feet, and 1 foot in length.

### 2.2. Description of DWV System

The plumbing system was derived from the plans for a simple single-bath, slab-on-grade residence with kitchen and laundry facilities. For the bathroom the fixtures consisted of a 20″ x 18″ ledge-back lavatory, a 5-foot recessed bathtub, and a siphon-jet-type water closet. For the kitchen the fixtures were a 32″ x 21″ two-compartment, flat-rim kitchen sink, and an automatic clothes washer. Figures 2 and 3 are schematic

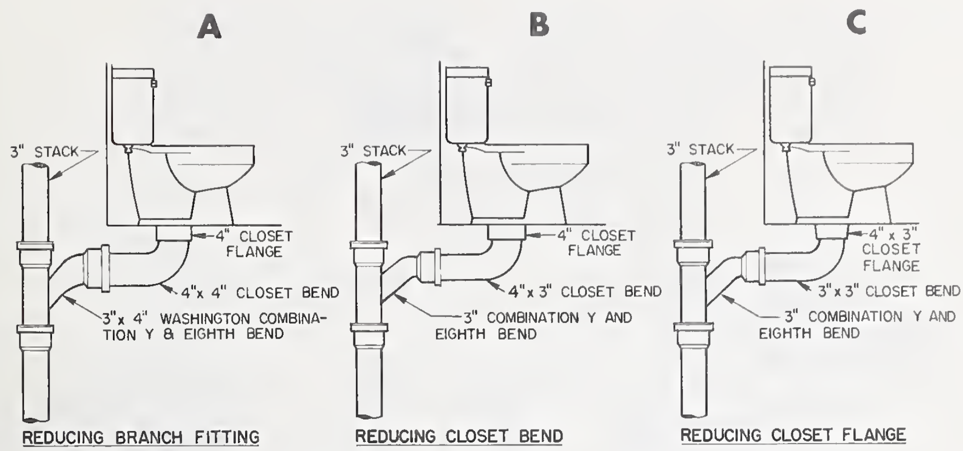


FIGURE 4. *Several methods for connecting a floor-outlet water-closet bowl to a 3-in soil stack.*

representations of the DWV system. Figure 4 shows the method used to connect the water closet to the soil stack, and indicates other methods that are often used. The water closet was connected to the soil stack by use of a 4″ x 6″ x 16″ closet bend connected into a 3″ x 4″ Washington reducing combination wye-and-eighth bend, as in figure 4(A).

The main building drain, soil stack, and soil vent (stack vent) were constructed of service-weight nominal 3-in cast iron hub-and-spigot soil pipe. The branch of the building drain serving both the kitchen sink and the automatic clothes washer was constructed of service-weight nominal 2-in cast iron soil pipe for the initial tests, but was later increased to 3-in size as described herein. A slope of ¼-in/ft was established for the drains. All the soil pipe joints were made with neoprene rubber gaskets with the exception of the joint to the water closet fitting and the connections to galvanized steel pipe. Except for the soil stack, the vertical cast iron drains for the individual fixtures terminated with 2-in cast iron hubs extending 4 inches above the floor to simulate slab-on-grade construction. Schedule 40 galvanized steel pipe was caulked into these hubs and extended vertically to serve as waste stacks and vents for the individual fixtures. The steel portions of the waste stack were 1½-in diam for the lavatory, sink and bathtub, and 2-in for the clothes washer. In the initial tests, all of the vent piping except for the soil vent was constructed of 1½-in diam schedule 40 steel pipe. In later tests provisions were made for the use of ½-in (i.d.) flexible plastic tubing for all of the dry vents beginning about 5 ft above floor level, as shown in figure 3.

Combination wye-and-eighth bends and long-sweep quarter bends were used elsewhere in the drainage piping with the exception that the 1½-in trap arm of the bathtub was connected to the bathtub vertical waste pipe below the floor level through a 2″ x 1½″ tapped sanitary tee.

The roughed-in drain piping was subjected to a 15-ft head of water with no evidence of leaks. The completed system was subjected to air pressure equivalent to a 2-in water column for a period of one-half hour. Since the indicated pneumatic pressure remained essentially constant a tight system was confirmed.

## 2.3. Approach to Measurement and Test Control

### 2.3.1. Measurement

Instrumentation was provided for the indication and recording of numerical values for parameters that described the hydraulic and pneumatic performance characteristics of the plumbing system, e.g., trap-seal retention, pneumatic pressures, water depth, etc.

Residual trap seals in the P-traps of the lavatory, the sink, and the clothes washer were measured with piezometers fabricated from glass tubing with attached graduated scales. The residual seals of the water closet and the bathtub were measured with electric point gages. These methods are illustrated in figure 5.

Fluctuating or rapidly changing pneumatic pressures and also the water depths were measured with strain-gage bridge-type pressure transducers and recorded on a multichannel recording oscillograph. Miniature pitot tubes were used to sense the air movement in the vents. Pressures in pipes were transmitted to the transducers or indicating devices through short lengths of plastic tubing leading from ⅛-in NPT fittings screwed into tapped openings in the pipe walls. Figure 6 shows the locations of the stations at which these measurements were made.

Dry air at atmospheric pressure (14.7 psia) and a temperature of 60 ° F was assumed in computing air velocities from measurements with the pitot tubes located in the vents. The effects of humidity and temperature under operating conditions were considered negligible for the purposes of this work. Mean velocity was assumed to be 80 percent of the indicated centerline velocity. The error introduced by this assumption is probably the largest source of error in the measurement of air rates in the vents. The greatest uncertainty in this experimentation was lack of information on the

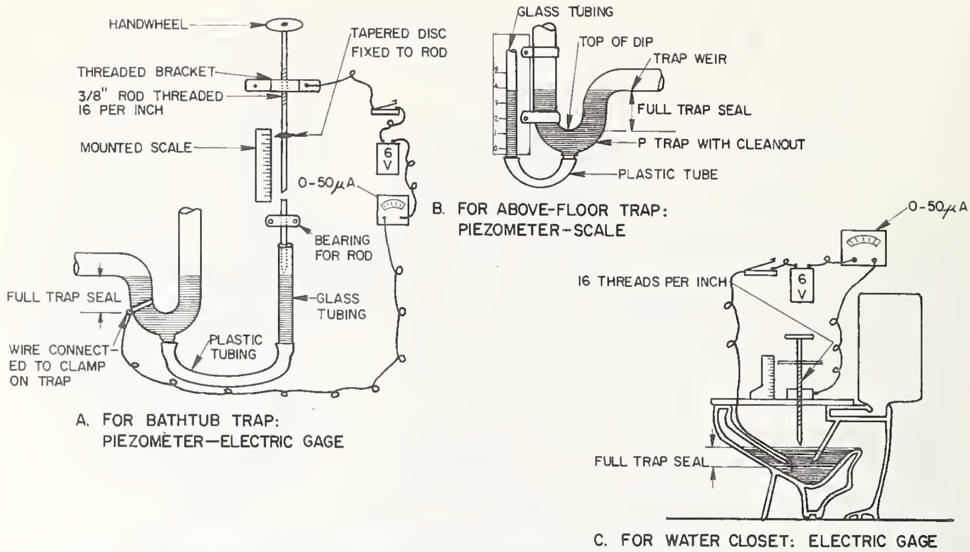


FIGURE 5. *Two methods for measuring trap-seal reduction/retention (one-story, slab-on-grade system).*

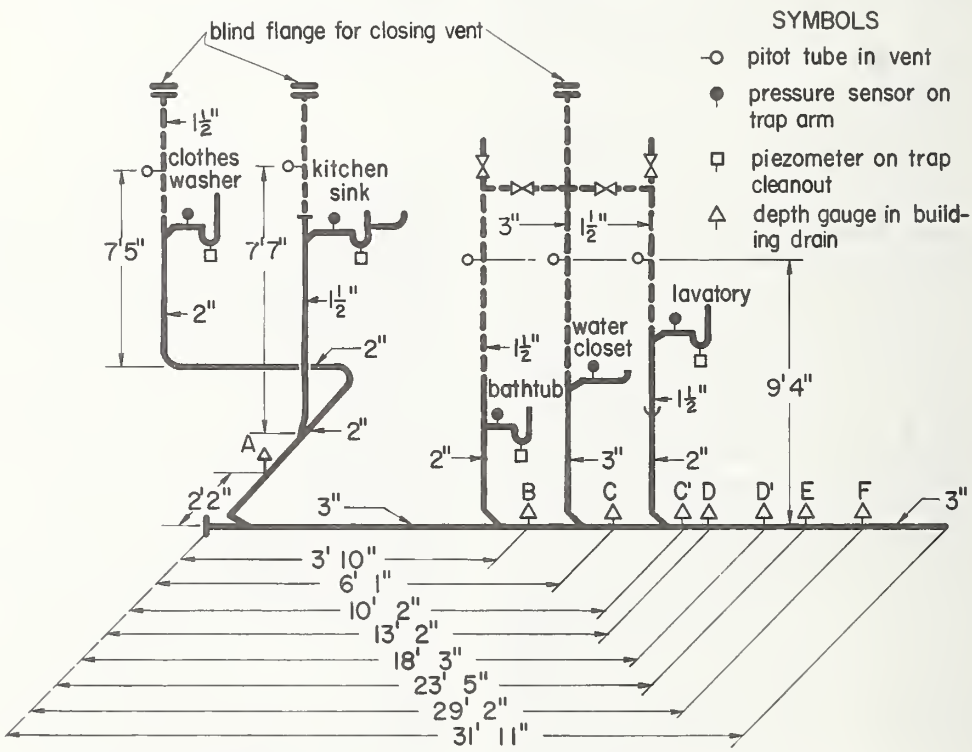


FIGURE 6. *Locations of measurement stations on one-story, slab-on-grade DWV test system.*

velocity profiles at the sections where the pitot tubes were placed. The velocity coefficients (i.e., the ratio of mean velocity to centerline velocity) determined by other experimenters range from 0.75 to 0.90. depending on a number of factors [10]. Thus, indicated air flow rates obtained by the procedure used could be in error by perhaps as much as ±10 percent. The anticipated application of such data would not require greater precision.

Information on the velocity of water flow in the building drain was obtained in two different ways. To obtain an estimate of *average velocities* between selected measurement stations (D and E, and E and F), the time intervals between the initial impact of the water at the upstream and downstream stations were determined from the multichannel oscillograph record of the outputs of the pressure transducers that monitored the depth of water during selected fixture load-

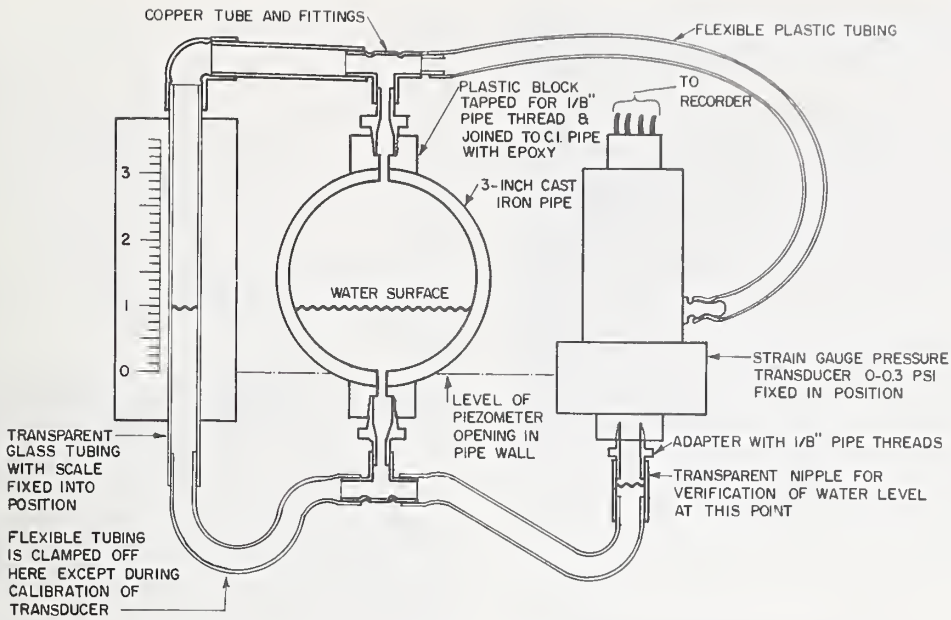


FIGURE 7. *Method for measurement of varying water depth in building drain (one-story, slab-on-grade system).*

ings. The average velocity was computed as the distance between stations divided by the time interval obtained as described. To obtain an estimate of the *peak velocity* as a function of distance above the invert of the building drain, a vertical traverse with a pitot tube was made with a selected hydraulic loading. It was necessary to repeat the loading at each setting of the pitot tube on its traverse. In retrospect some doubt exists about the significance of the pitot tube measurements for two reasons: (1) the response time of the pitot-tube measuring system was not determined and (2) the measurement procedure did not prevent air from entering the pitot tube. Because of these uncertainties the measurements are not included in this paper.

The lavatory, bathtub, and sinks were calibrated to determine the average rate of discharge and duration of discharge for selected water depths above the rim of the outlet fitting. The water closet was calibrated on a mechanical integrating device [8] which provided data for computing average discharge rates over successive short time intervals during fixture operation. The automatic clothes washer discharges were collected in a calibrated container to obtain the measurements needed for flow rate computations. More recently, the same clothes washer has been calibrated using a modern electronic load-cell weighing system as indicated in section 2.4.1.

Except where stated otherwise, the pressure of the water supply for the fixtures on the test system was maintained at approximately 50 psig (estimated tolerance 3 psi) by means of an adjustable pressure regulator. The source of supply was a 100 psig high-pressure water line.

[8] Shown on page 19 of NBS Monograph 86 [11].

The clothes washer had two distinct successive events: a drain event followed by a spin-spray event. The sprays comprised 4 discharges of 7 s duration each over a period of 2 min. The drain event discharged 16.4 gal of water during 60 s. The sprays discharged $4\frac{3}{4}$-gal during 120 s.

The method used for determining water depth in the building drain utilized a pressure transducer as shown in figure 7. Comparison of peak-depth values, obtained from an oscillograph record of the pressure transducer output, with visual determinations using a sight glass and scale indicated agreement within about ±5 percent, based on a number of comparisons with individual fixture discharges

### 2.3.2. Test-Load Selection, Designation, and Application

#### 2.3.2.1 Test-Load Selection

The combinations of fixture discharges used covered a wide range of loads, from single-fixture loads to all fixtures discharged. Many loads used were probably much more severe than representative service loads.

For comparison, it may be of interest to note that a guide for selecting fixture loads for testing single-branch-interval systems recently suggested by Wyly and Sherlin [12] indicates that in a system comprising five fixtures the discharge of three fixtures together would be a reasonable test load. Many of the test loads employed comprised the discharge of three or more fixtures together.

#### 2.3.2.2. Test-Load Designation

To simplify and shorten the descriptions of fixture loadings, a code has been devised that identifies the

fixtures, comprising the load, as well as the loading sequence. For the fixtures shown in figures 2, 3, and 6, the individual fixtures are coded B = bathtub, C = automatic clothes washer, J and K = the two individual compartments of the kitchen sink (J + K if discharged together), L = the lavatory, and W = the water closet. A time delay between the initiation of discharges from different fixtures is indicated by a numeral. For example W, 2. (B+J) = the washing machine followed 2 seconds later by the simultaneous discharge of the bathtub and the J-compartment of the kitchen sink; C, 4, W, 2, (B+J) = the clothes washer followed 4 seconds later by the water closet, and then an additional 2 seconds later by the simultaneous discharge of the bathtub and the J-compartment of the kitchen sink; All=all fixtures discharged simultaneously; and All —L=all fixtures except lavatory discharged simultaneously. This code has been used in presenting and discussing the test results from the one-story system.

#### 2.3.2.3. Test-Load Application

The discharging of fixtures was accomplished by means of electric solenoids which in the case of all fixtures other than the water closet and the automatic clothes washer pulled the drain plugs completely out of the water in the fixtures to eliminate interference to the flow. The water closet was actuated by a solenoid acting through the flush-tank linkages. Each of the solenoids was controlled by a single-pole, single-throw toggle switch. A toggle switch was used to operate the automatic clothes washer which was prefilled and preset on the drain event. By using a digital seconds counter (timer) a predetermined schedule of sequenced discharges could be imposed on the system by a single operator manipulating the switches while watching the timer.

## 2.4. Findings

The tests on the one-story, slab-on-grade system provided significant information on trap-seal retention as affected by the following test conditions:

1. All vents open (sized according to original design as shown in fig. 2).
2. Complete closure of all the vents.
3. Complete closure of some of the vents, with all others completely open
4. Size-reduction of all the vents and the use of a manifold vent terminal which was either open or closed.

For clarity, the findings are presented separately under each of the above categories. This is necessary because there were significant differences in the test system and in the test procedure that require separate presentation.

### 2.4.1. Fixture Calibrations

Data obtained from the calibration of the fixtures are shown as figures 8, 9, 10, and 11. In figure 8 the

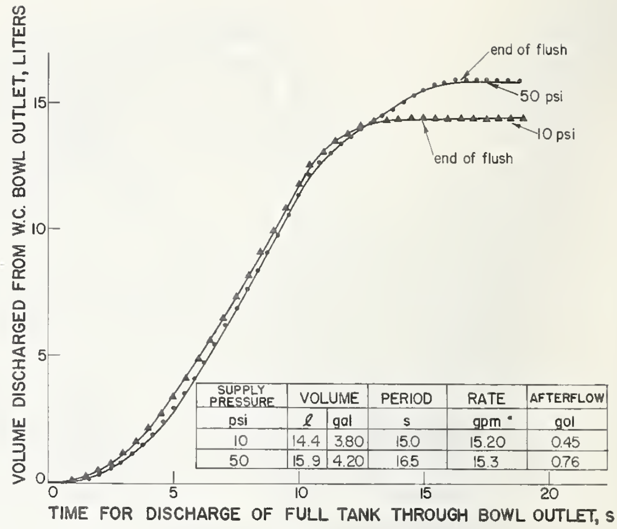


Figure 8. *Hydraulic calibration data for water closet.*

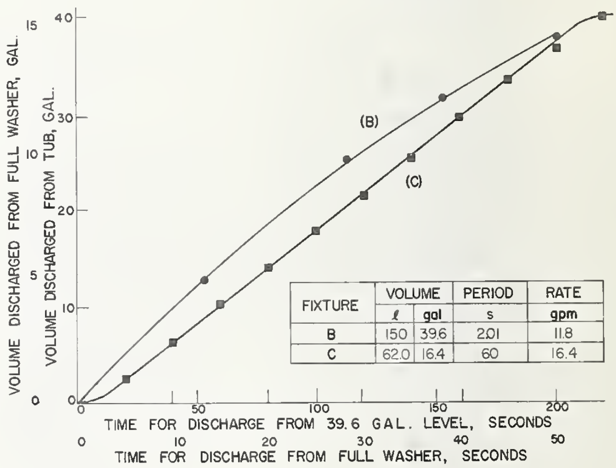


Figure 9. *Hydraulic calibration data for bathtub and clothes washer.*

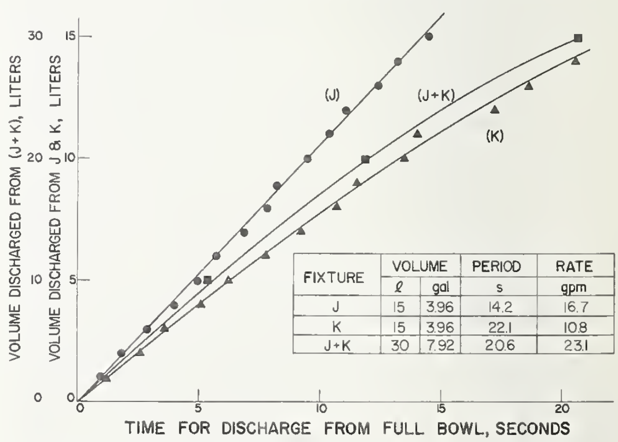


Figure 10. *Hydraulic calibration data for two-compartment kitchen sink.*

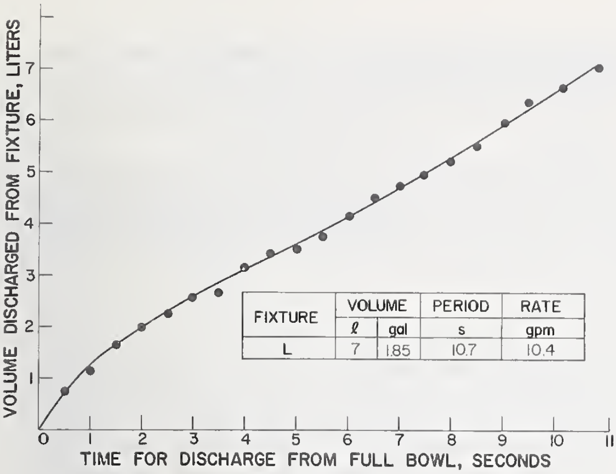


Figure 11. *Hydraulic calibration data for lavatory.*

water closet data depicts the discharge characteristic for operating pressures of 50 psi and 10 psi. The volume was measured in liters in graduated cylinders. Through use of conversion factors the volume has been converted to U.S. gallons in the tabulated computation. The average tabulated flow rate was calculated by using the time interval measured from beginning of discharge to the last trickle prior to the afterflow. Over the straighter portion of the calibration curve spanning the 5- to 10-second interval, a higher flow rate may be calculated to be 26.8 gpm. Calibration curves for the bathtub and for the clothes washer are shown in figure 9. The calibration data were obtained for volumes in the tub of 39.6 gal (9.05 in of depth) and for 26.4 gal (6.75 in of depth).

At 39.6 gal of initial volume the average flow rate was 11.8 gpm and at 26.4 gal it was 10.9 gpm. A simple extrapolation from these two values of flow rate gives a value of 10.8 gpm at 23.8 gal of volume (5.75 in of depth). An initial volume of 23.8 gal was agreed upon for the purpose of standardizing the contribution of the bathtub to the test loads.

In figure 10 calibration curves are shown for compartments (J) and (K) of the sink separately and for the two compartments (J+K) discharged simultaneously. Each compartment was filled with 15 liters of water. A pronounced difference existed in the flow rate of the two compartments. The reader is cautioned to note that the curve for (J+K) is plotted against an ordinate of double the size for (J) and for (K).

The difference in flow rates for the two compartments may be explained as a phenomenon associated with the arrangement of the drain piping. For compartment (K) the water discharged vertically downward through a tee into the trap whereas for compartment (J) the water would discharge vertically downward to an elbow and then horizontally to the tee at (K). When compartment (K) was discharged and compartment (J) was empty, the pneumatic effect of (J) on (K) was similar to that caused by the overflow feature of a lavatory. In work done at NBS in 1939, and confirmed by later studies reported in Housing Research Paper 31 [9], it was established that when the entrance to the lavatory overflow was sealed the time required to empty the fixture could be substantially reduced.

When compartment (J) is discharged it may be that as the water enters the tee beneath (K), a portion of the water is directed upward to seal off the drain from the atmosphere as a "standing plug." Thus, essentially, compartment (J) discharges similarly to a lavatory with a closed overflow and compartment (K) discharges similarly to a lavatory with an open overflow.

In figure 11 a typical calibration curve is shown for the lavatory that was used in the one-story study.

The calibration curves are typical of others obtained for these fixtures. One of the causes for variation between replicate curves obtained for bathtub, sink or lavatory is the occasional formation of a vortex which allows venting. Such venting will usually slow down the flow; however, if the fixture and fitting are so designed as to permit an occasional air lock to form, then a vortex may vent the air lock and speed up the flow.

### 2.4.2. Tests With All Vents Either Open or Closed

#### 2.4.2.1. Test Procedure

With all vents open, each fixture was discharged individually. Water depths and average velocities were measured in the 3-in building drain, air flow rates in the vents were determined, and trap-seal reductions were measured. A velocity traverse was made at station "D" during the water closet discharge.

Because representative loads for a 5-fixture system probably should involve more than a single fixture, a 3-fixture load was next applied. This comprised the discharge of the water closet, followed two seconds later by the simultaneous discharge of the bathtub and the two compartment kitchen sink. A similar but still heavier load was next applied, comprising the above-described load superimposed on the washing machine discharge during the time the washing machine was draining from full condition. The washer was started four seconds prior to the initiation of the water closet discharge. Finally, all fixtures were discharged simultaneously. For each of these three multi-fixture loadings measurements were made similar to those described above for the individual fixtures.

For the condition of all vents closed, fixtures in the system were operated as described for all vents open, and similar measurements were made, except that measurements of pneumatic pressures on the drain sides of the idle traps were made instead of air flow rates in the vents.

With all vents closed, some of the loads resulted in excessive reduction in the trap seals of the sink and/or the clothes washer. Evidently, substantial filling of the 2-in branch of the building drain serving the sink and clothes washer sometimes resulted in induced siphonage of one or more of these two traps. Had the branch of the building drain serving these two fix-

TABLE 1. *Summary of results:*[h] *Comparison of functional performance for all (customary size) vents either open or closed, with various clean-water loads (one-story, slab-on-grade system*[a]*)*

| Description of fixture discharge load | Symbols defining load[b] | All vents open | | | All vents closed | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average velocity in drain, fps[c] | | Trap-seals significantly affected by loading | Average velocity in drain, fps[c] | | Trap-seals significantly affected by loading | Max trap-arm pressure excursions, inches of water column[g] | Trap-seal reductions, inches |
| | | (D-E) | (E-F) | | (D-E) | (E-F) | | | |
| Bathtub | B | 2.6 | 2.9 | None | 2.9 | 2.6 | None | 0.00 | 0.0 |
| Automatic clothes washer | C | 3.0 | 2.9 | None | 3.0 | 2.9 | Sink[d]<br>Bathtub | +0.3, −0.1<br>Slight± | 0.1<br>0.0 |
| Kitchen sink, compartment not over trap | J | 2.9 | 2.9 | None | 3.4 | 2.9 | Clothes washer<br>Sink[d]<br>Bathtub | −2.7<br>—<br>−0.1 | 2.0<br>0.9<br>Slight |
| Kitchen sink, compartment over trap | K | 2.6 | 2.9 | None | 2.6 | 2.9 | Bathtub<br>Clothes washer | −0.1<br>−1.0 | 0.0<br>0.4 |
| Kitchen sink, both compartments | J+K[d] | 3.4 | 2.9 | None | 3.7 | 3.4 | Bathtub<br>Clothes washer<br>Sink[d] | −0.2<br>−2.4<br>— | Slight<br>1.8<br>1.1 |
| Lavatory | L | 2.8 | 2.9 | None | 3.4 | 2.9 | Sink[d] | −0.1 | 0.1 |
| Water closet | W | 2.6 | 2.9 | None | 3.1 | 2.9 | Bathtub | +0.2 | 0.1[e] |
| The water closet was discharged and followed two seconds later by the simultaneous discharge of the bathtub and compartment (J) of the two compartment sink | W, 2, (B+J) | 3.9 | 3.3 | None | 3.3 | 3.6 | Clothes washer<br>Sink[d] | −2.7<br>— | 1.4<br>1.6 |
| The clothes washer was discharged and followed four seconds later by the load described immediately above | C, 4, W, 2, (B+J) | 3.4 | 2.9 | None | 2.9 | 3.8 | Lavatory<br>Sink[d]<br>Clothes washer | −2.2<br>—<br>— | 0.8<br>2.1<br>1.9[f] |
| All fixtures discharged simultaneously | All | 2.2 | 3.4 | None | 3.3 | 3.3 | Sink[d]<br>Lavatory<br>Water closet | —<br>−3.6<br>— | 0.8<br>1.8<br>0.5 |

[a] See figure 2 and 6.

[b] These and similar symbols will be used thoroughout this paper to identify the fixtures that comprise a test load and also to define the intervals of time between the initiation of the segments or a sequential load.

[c] Travel distances are from: D-E 10 ft-3 in and from E-F 5 ft-9 in.

[d] The two-compartment sink has a single trap under compartment K (does not have a food-waste disposal unit).

[e] Also observed at kitchen sink trap.

[f] Initial trap-seal depth of clothes washer is recovered when spray operates.

[g] Where only a negative or only a positive value is listed, the value with the opposite sign was substantially lower in numerical value, so was not recorded.

[h] Calculated velocities have been rounded to the nearest tenth of a foot per second, and trap arm (vent) pressures and trap-seal reductions to the nearest tenth of an inch. Probably greater resolution was not possible with the instrumentation and procedures used.

tures been 3-in in diameter, effective air relief might have been accomplished over the water in the building drain, since the 3-in drain would not have been flowing full.

Average velocities in the main building drain computed as described in section 2.3.1 and shown in table 1, do not appear to be significantly affected by closing all the vents.

#### 2.4.2.2. Results

Table 1 shows results of the initial tests on the one-story, single-bath system with code-size vents either all open or all closed. The tests with individual fixtures define the minimum loads utilized and provide a lower reference for the comparison of effects of various other loadings.

With all vents open, no significant trap-seal reductions were observed for any fixture loading applied, as indicated in table 1. The two columns at the right of the table give the trap-seal reductions and associated vent pressure excursions for the trap most affected, with all vents closed. The only traps losing in excess of the inch of water seal were those serving the sink and clothes washer.

#### 2.4.2.3. Discussion

With all vents open, no trap-seal reductions occurred with any of the fixture loadings; therefore it may be concluded that the venting was adequate to protect the trap seals even under severe loading conditions. Thus, the adequacy of the code-sized vents was confirmed .

### 2.4.3. Tests With Some Vents Closed

#### 2.4.3.1. Test Procedure

For these studies the experimental plumbing system was equipped with gate valves and removable blind flange plates at the vent terminals (see figure 6). This permitted each of the individual vents to be vented directly to the atmosphere instead of through the main stack vent when this was required. This arrangement was made to expedite the opening and closing of the various vents in different combinations of open and closed vents. Preliminary tests with a given hydraulic loading showed no detectable differences in trap-seal reductions or in air-flow rates in the individual fixture vents that could be attributed to routing the bathtub or lavatory vents directly to the atmosphere rather than through the stack vent.

Two more water-depth measuring stations and pressure transducers (C′ and D′) were added to the building drain (see fig. 6).

A more-sensitive pressure transducer (full-scale range $\pm 0.01$ psid) was added to increase sensitivity in the measurement of air speed in the vents, using pitot tubes, as described in section 2.3.1 and shown in figure 6. Previously the lowest-range transducer used was $\pm 0.05$ psid.

The effects of the selected loadings on trap-seal reductions, air flow rates in the open vents, and water depths in the building drain were investigated for all combinations of four vents closed and one vent open and for three vents closed and two vents open.

A number of fixture discharge patterns were utilized in these tests as indicated in table 2. These discharges were picked by trial and error in an attempt to identify load patterns giving the greatest trap-seal reduction for particular selections of open or closed vents. A number of the loads utilized were three-fixture loads. A recently-published guide for selecting test loads for one-interval systems [5] gives three fixtures as a reasonable test load for such a system comprising five fixtures. Thus, the use of test loads comprising three fixtures in evaluating the performance of the complete system seems reasonable.

#### 2.4.3.2. Results

In table 2 the test data have been organized around the column that shows which vents were closed in the tests that produced the data. For each combination of open and closed vents, one of the hydraulic loadings consisted of the water closet discharge followed two seconds later by the simultaneous discharge of the bathtub and one compartment of the kitchen sink (W,2,(B+J)). The other fixture discharge loadings were those picked by trial and error in an attempt to explore the effects of a broad range of potential loads. Table 2 categorizes for each test loading the trap-seal reductions as being excessive or a failure (F), or satisfactory (S) and identifies the fixtures where excessive trap-seal reductions occurred, based on the criterion that reductions exceeding 1 in are excessive. Peak air flow rates were measured only for the load (W,2,(B+J)).

Water depths were measured at four places (D, D′, E, F) along the length of building drain (see fig. 6). The maximum value of the water depths has been recorded in table 2 as a percentage of the drain diameter. The corresponding depths expressed in inches may be obtained by multiplying the represented percentages by the factor 0.03. Figure 12 consists of a family of curves showing peak water depth in the building drain at several stations along the length of the building drain. Each curve is identified by a fixture discharge or the combination of fixture discharges that created the peak water depth.

Average flow rates were assigned to the several combinations of fixture discharges by adding the rates for the individual fixtures involved in the combination loading (see calibration data, section 2.4.1 and figs 8–11). It is recognized that the time delays between individual fixture discharges as well as other factors undoubtedly affected the discharge rate at any given station along the building drain. The assigned values. therefore, are to be taken only as approximations of the true discharge rates within the drain and as providing a simplified means of characterizing the magnitude of the loadings, in the absence of more precise data.

TABLE 2. *Summary of results: Comparison of functional performance for different combinations of open and closed (customary-size) vents, with various clean-water loads (one-story, slab-on-grade system [a])*

| Item No. | Test load: fixture combinations/ sequences [cd] | Number of active traps | Vents closed [b] | | | | | Trap performance [a] | Trap seals reduced by more than 1 in [a] | | | | | Maximum depth of water in building drain % of diam [a] | Peak air flow rates in vents in gpm [a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory |
| 1 | W, 2, (B+J) | 3 | X | X | X | X | X | F [h] | X | X | | | | 62 | 0 | 0 | 0 | 0 | 0 |
| 2 | All | 5 | X | X | X | X | X | F | X | | | | X | 76 | 0 | 0 | 0 | 0 | 0 |
| 3 | W, 2, (B+J) | 3 | | X | X | X | X | S | | | | | | 56 | 19 | 0 | 0 | 0 | 0 |
| 4 | All | 5 | | X | X | X | X | F | | | | | X | 83 | — | 0 | 0 | 0 | 0 |
| 5 | W, 2, (B+J+K) [ef] | 3 | | X | X | X | X | F | | X | | | | 88 | — | 0 | 0 | 0 | 0 |
| 6 | W, 2, (B+J+K) [g] | 3 | | X | X | X | X | S | | | | | | 62 | — | 0 | 0 | 0 | 0 |
| 7 | W, 2, (B+J) | 3 | X | | X | X | X | S | | | | | | 54 | 0 | 18 | 0 | 0 | 0 |
| 8 | W, 2, (B+J+K) | 3 | X | | X | X | X | S | | | | | | — | 0 | — | 0 | 0 | 0 |
| 9 | All | 5 | X | | X | X | X | F | X | | | | X | — | 0 | — | 0 | 0 | 0 |
| 10 | All − C | 4 | X | | X | X | X | S | | | | | | — | 0 | — | 0 | 0 | 0 |
| 11 | W, 2, (B+J) | 3 | X | X | | X | X | F | X | X | | | | 61 | 0 | 0 | 23 | 0 | 0 |
| 12 | C, 1, J, 1, W | 3 | X | X | | X | X | F | X | | | | | — | 0 | 0 | — | 0 | 0 |
| 13 | All | 5 | X | X | | X | X | F | X | | | | | — | 0 | 0 | — | 0 | 0 |
| 14 | W, 2, (B+J) | 3 | X | X | X | | X | F | | X | | | | 59 | 0 | 0 | 0 | 51 | 0 |
| 15 | C, 2, (J+L) | 3 | X | X | X | | X | F | X | | | | | — | 0 | 0 | 0 | — | 0 |
| 16 | C | 1 | X | X | X | | X | F | X | | | | | — | 0 | 0 | 0 | — | 0 |
| 17 | W+L | 2 | X | X | X | | X | S | | | | | | — | 0 | 0 | 0 | — | 0 |
| 18 | W, 2, (B+J) | 3 | X | X | X | X | | F | X | | | | | 59 | 0 | 0 | 0 | 0 | 27 |
| 19 | All − L | 4 | X | X | X | X | | F | X | X | | | | — | 0 | 0 | 0 | 0 | — |
| 20 | W, 2, (B+J) | 3 | | | X | X | X | S | | | | | | 51 | — | 26 | 0 | 0 | 0 |
| 21 | C+J+K | 2 | | | X | X | X | S | | | | | | — | — | — | 0 | 0 | 0 |
| 22 | All | 5 | | | X | X | X | F | | | | | X | — | — | — | 0 | 0 | 0 |
| 23 | W, 2, (B+J) | 3 | | X | | X | X | F | | | | | | 59 | 17 | 0 | 19 | 0 | 0 |
| 24 | C+L+W | 3 | | X | | X | X | S | | | | | | — | — | 0 | — | 0 | 0 |
| 25 | All − (J+K) | 4 | | X | | X | X | S | | | | | | — | — | 0 | — | 0 | 0 |
| 26 | W, 2, (B+J) | 3 | | X | X | | X | S | | | | | | 55 | 18 | 0 | 0 | — | 0 |
| 27 | W, 2, C | 2 | | X | X | | X | S | | | | | | — | — | 0 | 0 | — | 0 |
| 28 | C, 2, (J+K), 1, W | 3 | | X | X | | X | F | | X | | | | — | — | 0 | 0 | — | 0 |
| 29 | All − L | 4 | | X | X | | X | S | | | | | | — | — | 0 | 0 | — | 0 |
| 30 | W, 2, (B+J) | 3 | | X | X | X | | S | | | | | | 59 | 13 | 0 | 0 | 0 | 16 |
| 31 | C, 2, (J+K), 3, W | 3 | | X | X | X | | F | | X | | | | — | — | 0 | 0 | 0 | — |
| 32 | C, 3, B | 2 | | X | X | X | | S | | | | | | — | — | 0 | 0 | 0 | — |
| 33 | All | 5 | | X | X | X | | F | | X | | | | — | — | 0 | 0 | 0 | — |
| 34 | W, 2, (B+J) | 3 | X | | | X | X | S | | | | | | 79 | 0 | 26 | 19 | 0 | 0 |
| 35 | J, 2, (L+W) | 3 | X | | | X | X | S | | | | | | — | 0 | — | — | 0 | 0 |
| 36 | (J+K), 3, (L+W) | 3 | X | | | X | X | S | | | | | | — | 0 | — | — | 0 | 0 |
| 37 | C+J+K | 2 | X | | | X | X | F | X | | | | | — | 0 | — | — | 0 | 0 |
| 38 | All − L | 4 | X | | | X | X | F | X | | | | | — | 0 | — | — | 0 | 0 |
| 39 | W, 2, (B+J) | 3 | X | | X | | X | S | | | | | | 64 | 0 | 19 | 0 | — | 0 |
| 40 | C+J+K | 2 | X | | X | | X | F | X | | | | | — | 0 | — | 0 | — | 0 |
| 41 | W, 2, (B+J) | 3 | X | | X | X | | S | | | | | | 58 | 0 | 14 | 0 | 0 | 28 |
| 42 | W, 2, (B+J+K) | 3 | X | | X | X | | S | | | | | | — | 0 | — | 0 | 0 | — |
| 43 | L, 2, (B+J+K+W) | 4 | X | | X | X | | S | | | | | | — | 0 | — | 0 | 0 | — |
| 44 | C+J+K | 2 | X | | X | X | | F | | | | | | — | 0 | — | 0 | 0 | — |

TABLE 2. *Summary of results: Comparison of functional performance for different combinations of open and closed (customary-size) vents, with various clean-water loads (one-story, slab-on-grade system* [a]*)*—Continued

| Item No. | Test load: fixture combinations/ sequences [c d] | Number of active traps | Vents closed [b] | | | | | Trap performance [a] | Trap seals reduced by more than 1 in [a] | | | | | Maximum depth of water in building drain % of diam [a] | Peak air flow rates in vents in gpm [a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory |
| 45 | W, 2, (B+J) | 3 | X | X | | | X | F | | X | | | | 62 | 0 | 0 | 17 | — | 0 |
| 46 | All | 5 | X | X | | | X | F | X | | | | | — | 0 | 0 | — | — | 0 |
| 47 | J | 1 | X | X | | | X | F | X | | | | | — | 0 | 0 | — | — | 0 |
| 48 | W, 2, (B+J) | 3 | X | X | | X | | F | X | X | | | | 62 | 0 | 0 | 21 | 0 | 28 |
| 49 | B+J+W | 3 | X | X | | X | | S | | | | | | — | 0 | 0 | — | 0 | — |
| 50 | W, 3, (B+J) | 3 | X | X | | X | | S | | | | | | — | 0 | 0 | — | 0 | — |
| 51 | W, 4, (B+J) | 3 | X | X | | X | | S | | | | | | — | 0 | 0 | — | 0 | — |
| 52 | W, 6, (B+J) | 3 | X | X | | X | | S | | | | | | — | 0 | 0 | — | 0 | — |
| 53 | W, 2, (B+J) | 3 | X | X | X | | | S | | | | | | 66 | 0 | 0 | 0 | 51 | — |
| 54 | C, 2, (J+K) | 2 | X | X | X | | | F | X | X | | | | — | 0 | 0 | 0 | — | — |
| 55 | C, 2, (J+K), 1, B | 3 | X | X | X | | | F | X | X | | | | — | 0 | 0 | 0 | — | — |
| 56 | W, 2, C | 2 | | | | | | S | | | | | | 62 | — | 22 | 19 | — | — |
| 57 | All | 5 | | | | | | S | | | | | | 79 | — | — | — | — | — |

[a] See figure 6. A single test was made for each combination of vent arrangement and load.

[b] Vent dimensions: for the bathtub, clothes washer, and kitchen sink the vents were 1½-in diam × 9-ft long; for the water closet, 3 in diam × 10-ft long and for the lavatory 1½-in diam × 7-ft long. See figure 6 for methods of closing vents.

[c] B = bathtub, C = automatic clothes washer, J = compartment of the kitchen sink not over trap and K = compartment of the sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture, L = lavatory, W = water closet.

[d] Three types of symbols are used to designate the fixtures discharged to comprise a test load: (a) simultaneous discharge of group such as All = B+C+(J+K)+L+W, (b) partial simultaneous; All − (J+K) = all fixtures except the two-compartment kitchen sink, (c) sequential; W, 2, (B+J) = water closet followed by a 2-second pause followed by simultaneous discharge of the bathtub and compartment J of the kitchen sink.

[e] A single trap served the two-compartment sink (J+K).

[f] Small vortex in each compartment of the sink.

[g] Large vortex in each compartment of the sink.

[h] F = Failed (at least one trap seal was reduced by more than one inch).
S = Satisfactory, (no trap seal was reduced by more than one inch).

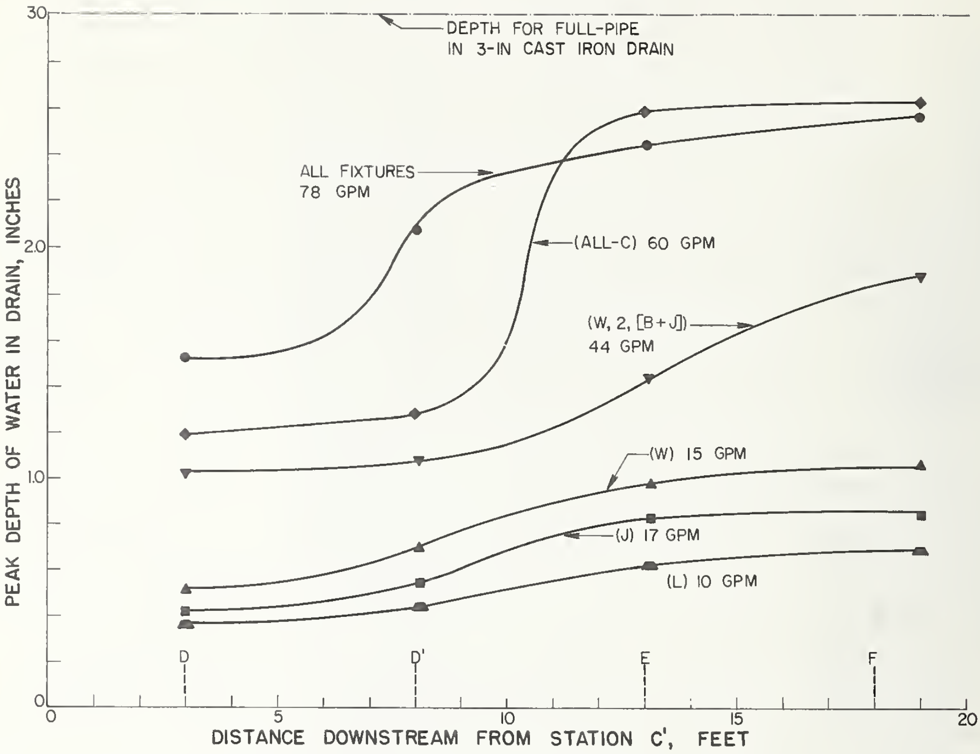


FIGURE 12. *Peak water depths at several stations in building drain, for various fixture loads (one-story, slab-on-grade system).*

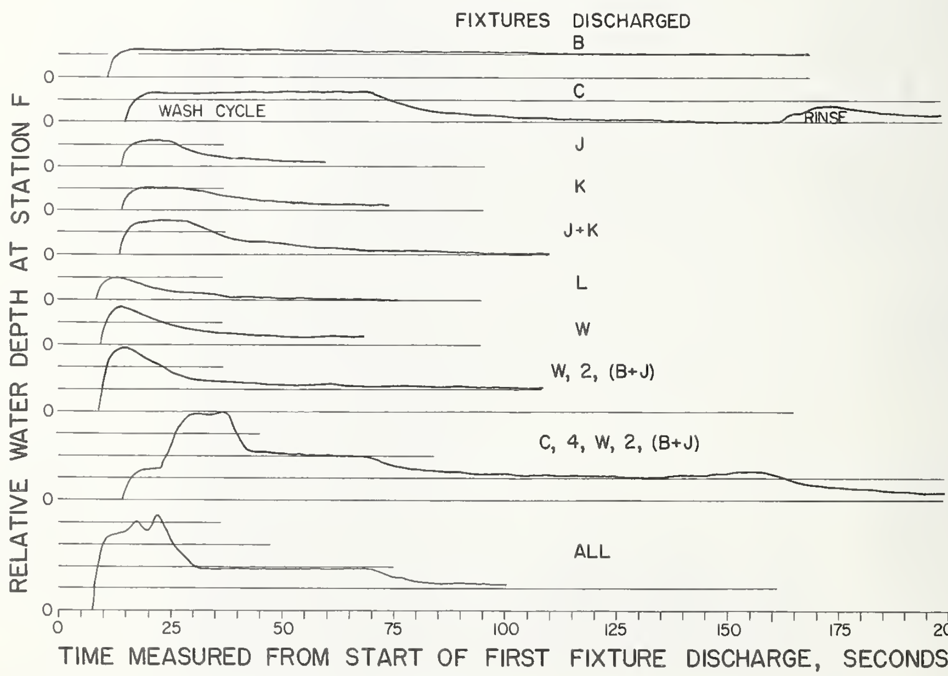


FIGURE 13. *Relative water depths in building drain produced during selected fixture discharges at station F (one-story, slab-on-grade system).*

Figure 13 shows measurements of relative water depth made at station F during the passage of several fixture loadings.

#### 2.4.3.3. Discussion

The data given in table 2 for the tests with some or all vents closed show that none of the loadings produced a failure of the water closet or bathtub trap seals, and that only the discharge of all fixtures together produced a failure of the lavatory trap seal. The data also show that all failures of the sink and/or clothes washer trap seals occurred when one or both of these two fixtures were discharged to comprise all or part of the hydraulic loading. This indicates that reductions in the trap seals of the clothes washer and the sink may have been caused by temporary complete filling of some part of the 2-in branch of the building drain serving these two fixtures, when one or both of the vents serving these fixtures were closed. If this were the case, venting through the air space over the water would have been inhibited.

Either phenomenon or a combination of the two seems possible since a 2-in drain with $n = 0.015$ and a slope of $\frac{1}{4}$ in/ft has a capacity of only about 17 gpm flowing full as computed by the Manning formula [13]. Because of the rougher-than-usual appearance of the soil pipe used in this study, and because of configuration effects that might have reduced computed capacities it is reasonable to suppose that the 2-in branch of the building drain was flowing full over a portion of its length during the discharge of the sink ($J = 16.4$ gpm, $J + K = 23.1$ gpm) or the clothes washer (16.4 gpm).

Further analysis of the pattern of the failures of the sink and clothes washer trap seals shows that failure of both occurred only when both vents were closed, and that failure of either trap seal occurred only when its vent was closed. It was surmised that improved performance, especially with either the sink or clothes washer vent closed, might be achieved by enlarging the building drain branch to 3-in diam.

A matrix arrangement of the data shown in tables 1 and 2 has been made in table 3, showing the effects of the various loads on the trap seals of the system when operated with no vents (all vents closed) or with combinations of one, two, or three vents open. The loadings are broadly grouped and listed progressively by the number of active traps contributing to the load. Within each such group the simultaneous loadings such as (C+L+W) precede sequential loadings such as C,2,(J+L). Also, sequential loadings involving two pauses are grouped after loadings that involve only one pause.

Within each strata of the tabulations resulting from the arrangement described above, the loadings are listed in alphabetical order according to the first letter in the coded descriptor. Further separation and ordering are based on the second, third, or fourth letter of the code. Within a strata of sequential loadings the duration of the first pause is next considered such that (C+J+W),2,B would precede (C+J+W),4,B. For a contrasting example, (C+J+L),4,B would precede (C+J+W),2,B. Finally, C,2,(J+K),2,W would precede C,2,(J+K),4,W.

The matrix demonstrates the value of hindsight and serendipity. For example, a loading thought to be reasonable (W,2,(B+J)) was selected and used for the particular combination of three vents open with the bathtub and lavatory vents closed, for all combinations with two open vents, for all combinations with one open vent, and for the condition of all vents closed. The location of the resulting trap-seal reduction data within the matrix, as in items 29, 31, and 35, clearly shows a progression of effects on the trap seals by degree of venting.

For items 29 and 31 the use of a single vent, such as the clothes washer vent or the kitchen sink vent, corrected the overload effect on the trap seals. In item 35 the use of the water closet vent only was not enough, but the combined vents of water closet and clothes washer were adequate to protect the trap seals.

For item 27, the single vent at the bathtub was inadequate but the addition of the clothes washer vent corrected the problem. At item 33, neither the single vent at the lavatory nor the combined effect of vents at lavatory and bathtub was sufficient. Data on the combinations of vents (B;C;L), (B;J;L), or (B;L;W) were not obtained, but since (B;C), (B;J) and (L;W) provided adequate venting, these three-vent combinations, created by adding the lavatory vent for two of the combinations and a bathtub vent for the other, probably would have resulted in satisfactory trap performance had they been tested.

For all of loadings tried when using the combination of three-vents, (C;J;W), adequate ventilation was obtained; however, in the 59 items listed in the table, only 20 represented tests with this combination.

For items 33, 37, 38, and 39, data were sought on the effect of varying the length of pause in the similar sequential loadings. For each of the tests there were one or more runs involving excess trap-seal reduction, but there was no general trend with the progressive change in the length of pause in these tests.

The results obtained with the very heavy loading(s) of items 48 through 56 showed that the particular combination of vents (C;J;W) provided adequate venting for the system under all combinations of loading resulting from simultaneously discharging any four fixtures in any combination. The results given by other items in the table suggest that this probably could be said also for any sequential discharge of two, three, or four fixtures.

Items 57, 58, 59 represent data for five fixtures discharged simultaneously. Item 59 shows that the vent combination (C;J;W) provided satisfactory venting with this load also.

The method of grouping the data by magnitude of loading and by degree of venting is useful in interpreting data from venting tests, would be purposeful in defining a systematic test progression at the stage when test plans are being made, and would provide a guide to aid in decisions on the need for continuing

TABLE 3. *Matrix of data from tables 1 and 2, arranged progressively by magnitude of loading and degree of venting*

| Item No. | Fixtures that comprise the test loading | Number of traps | | No open vents | Excessive trap-seal reduction | One open vent | Excessive trap-seal reduction | Two open vents | Excessive trap-seal reduction | Three open vents | Excessive trap-seal reduction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Active | Idle | | | | | | | | |
| 1 | B, K, L or W | 1 | 4 | (None) | None | | | | | (C; J; W) | None |
| 2 | C | 1 | 4 | (None) | C | (W) | C | (B; W) | C | (C; J; W) | None |
| 3 | J | 1 | 4 | (None) | C | | | (B; W) | C | | |
| 4 | (J+K) | 1 | 4 | (None) | C, J | | | | | (C; J; W) | None |
| 5 | (L+W) | 2 | 3 | | | (W) | None | | | | |
| 6 | B, 10, W | 2 | 3 | | | | | | | (C; J; W) | None |
| 7 | C, 2, B | 2 | 3 | | | | | | | (C; J; W) | None |
| 8 | C, 2, J | 2 | 3 | | | | | | | (C; J; W) | None |
| 9 | C, 2, L | 2 | 3 | | | | | | | (C; J; W) | None |
| 10 | C, 2, W | 2 | 3 | | | | | | | (C; J; W) | None |
| 11 | C, 2, (J+K) | 2 | 3 | | | | | (L; W) | C, J | | None |
| 12 | C, 2, (J+K) | 2 | 3 | | | | | | | (C; J; W) | None |
| 13 | C, 3, B | 2 | 3 | | | | | (C; L) | None | | |
| 14 | W, 2, C | 2 | 3 | | | | | (C; W) | None | | |
| 15 | (C+J+K) | 2 | 3 | | | | | (B; J) | None | | |
| 16 | (C+J+K) | 2 | 3 | | | | | (C; J) | C | | |
| 17 | (C+J+K) | 2 | 3 | | | | | (J; L) | C | | |
| 18 | (C+J+K) | 2 | 3 | | | | | (J; W) | C | | |
| 19 | (J+K), 2, W | 2 | 3 | | | | | | | (C; J; W) | None |
| 20 | (B+J+W) | 3 | 2 | | | | | (B; L) | C | | |
| 21 | (C+J+K+W) | 3 | 2 | | | | | | | (C; J; W) | None |
| 22 | (C+L+W) | 3 | 2 | | | | | (B; C) | None | | |
| 23 | (B+C), 5, (J+K) | 3 | 2 | | | | | | | (C; J; W) | None |
| 24 | C, 2, (J+L) | 3 | 2 | | | (W) | C | | | | |
| 25 | J, 2, (L+W) | 3 | 2 | | | | | (B; J) | None | | |
| 26 | (J+K), 3, (L+W) | 3 | 2 | | | | | (B; J) | None | | |
| 27 | W, 2, (B+J) | 3 | 2 | (None) | C, J | (B) | C, J | (B; C) | None | | |
| 28 | W, 2, (B+J) | 3 | 2 | | | | | (B; J) | None | | |
| 29 | W, 2, (B+J) | 3 | 2 | (None) | C, J | (C) | None | (C; J) | None | (C; J; W) | None |
| 30 | W, 2, (B+J) | 3 | 2 | | | | | (C; L) | None | | |
| 31 | W, 2, (B+J) | 3 | 2 | (None) | C, J | (J) | None | (J; W) | None | (C; J; W) | None |
| 32 | W, 2, (B+J) | 3 | 2 | | | | | (J; L) | None | | |
| 33 | W, 2, (B+J) | 3 | 2 | (None) | C, J | (L) | C | (B; L) | C, J | | |
| 34 | W, 2, (B+J) | 3 | 2 | | | | | (L; W) | None | | |
| 35 | W, 2, (B+J) | 3 | 2 | (None) | C, J | (W) | J | (C; W) | None | (C; J; W) | None |
| 36 | W, 2, (B+J) | 3 | 2 | | | | | (B; W) | C, J | | |
| 37 | W, 3, (B+J) | 3 | 2 | | | | | (B; L) | C | | |
| 38 | W, 4, (B+J) | 3 | 2 | | | | | (B; L) | C | | |
| 39 | W, 6, (B+J) | 3 | 2 | | | | | (B; L) | C | | |
| 40 | W, 2, (B+J+K) | 3 | 2 | | | (C) | J | | | | |
| 41 | W, 2, (B+J+K) | 3 | 2 | | | (C) | None | | | | |
| 42 | W, 2, (B+J+K) | 3 | 2 | | | (J) | None | (J; L) | None | | |
| 43 | C, 1, J, 1, W | 3 | 2 | | | (B) | C | | | | |
| 44 | C, 2, (J+K), 1, B | 3 | 2 | | | | | (L; W) | C, J | | |
| 45 | C, 2, (J+K), 1, W | 3 | 2 | | | | | (C; L) | J | | |
| 46 | C, 2, (J+K), 1, W | 3 | 2 | | | | | (C; W) | J | | |
| 47 | C, 5, (J+K), 5, W | 3 | 2 | | | | | | | (C; J; W) | None |
| 48 | All−C | 4 | 1 | | | (J) | None | | | | |
| 49 | All−L | 4 | 1 | (None) | C, J | (L) | C, J | | | | |
| 50 | All−L | 4 | 1 | | | | | (B; J) | C | | |
| 51 | All−L | 4 | 1 | | | | | (C; W) | None | | |
| 52 | All−(J+K) | 4 | 1 | | | | | (B; C) | None | | |
| 53 | L, 2, (B+J+K+W) | 4 | 1 | | | | | (J; L) | None | | |
| 54 | (B+C), 4, (J+K), 4, W | 4 | 1 | | | | | | | (C; J; W) | None |
| 55 | (B+C), 5, (J+K), 5, W | 4 | 1 | | | | | | | (C; J; W) | None |
| 56 | C, 4, W, 2, (B+J) | 4 | 1 | (None) | C, L, W | | | | | (C; J; W) | None |
| 57 | All | 5 | 0 | (None) | C, L | (B) | C | (B; W) | C | | |
| 58 | All | 5 | 0 | (None) | C, L | (C) | L | (C; L) | J | | |
| 59 | All | 5 | 0 | (None) | C, L | (J) | C, L | (C; J) | L | (C; J; W) | None |

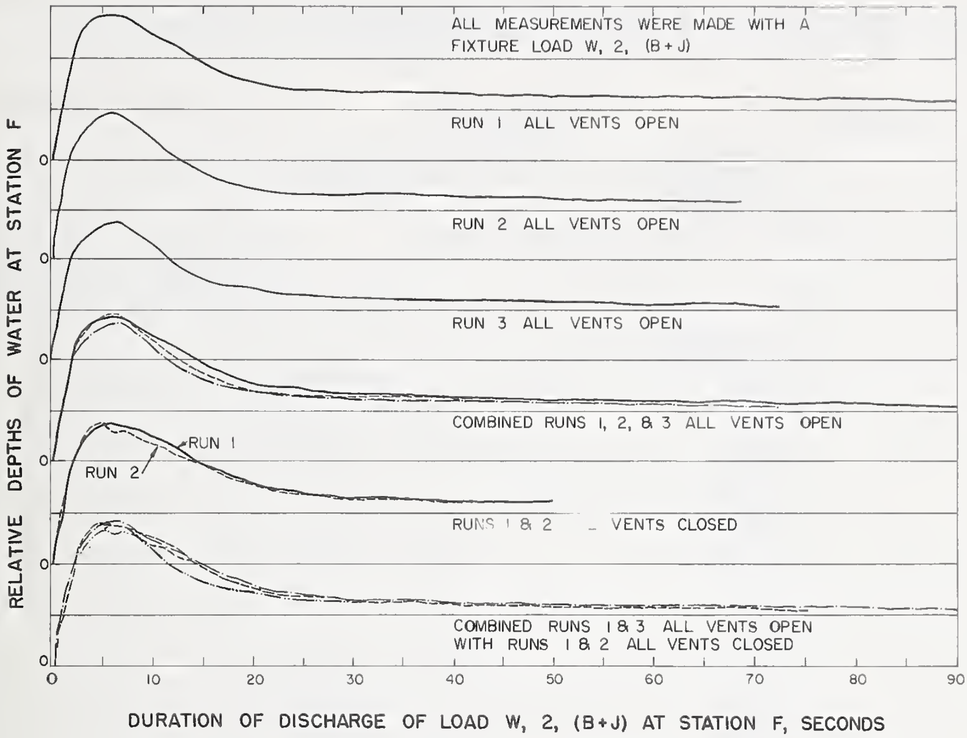


FIGURE 14. *Repeatability of depth measurements in building drain in successive tests with and without venting (one-story, slab-on-grade system).*

tests in a loading or venting progression after some measurements are completed.

The data of table 2 and figure 12 on maximum water depths in the main, 3-in building drain shows that none of the loads, including the discharge of all fixtures together, caused the drain to flow completely full. It is reasonable to suppose that with some vents closed or omitted, or with sizes reduced appreciably below usual values, critical demands for air may occur when horizontal drains flow full at some section(s), because under such conditions air relief through the air space over the water in the horizontal drain cannot be relied on to aid in the control of trap-arm pressure excursions. As expected, the maximum depths were generally associated with the greater rates of discharge into the system; however, the spatial distribution of the input points for a multi-fixture load appeared to influence the maximum depths.

The data of figure 12 show that for all of the six loadings, the maximum depths occurred at the station farthest down stream. This suggests that "cresting" of the intermittent hydraulic loads introduced into building drains may well occur at considerable distances downstream of the points at which they enter the building drain. This phenomenon was investigated experimentally in an earlier study of surge flow at NBS [11] and the findings in that study showed that the distance of travel in the building drain before "cresting" was influenced by drain slope, hydraulic roughness, type of stack-base fitting, drain diameter, and other factors. Distances of 15 to 66 ft were obtained with a 3-in drain in the earlier study. This contrasts with the belief expressed by the proponents of one single-stack system that the point of maximum depth occurs within four or five feet of the point of connection of a drainage stack with the building drain [14]. Whether the indicated difference in cresting distance in the building drain is a result of the differences in hydraulic design has not been determined.

The flow-profile data for several fixture loadings shown in figure 13 is important in that it suggests that it may be possible to infer which fixture or fixture combination produces a drain load by the analysis of the indicated water depth-time profile. This seems feasible for two reasons:

1. Repetitive discharges of selected fixtures or combinations, even with substantial variations in venting, yielded almost identical profiles (see fig. 14).
2. The characteristic profiles of individual fixtures appear to be distinguishable to a considerable degree even when two or more fixtures are discharged together or in sequence.

The possibilities for a successful application of this technique as a research tool in obtaining load data in occupied buildings depend on the ability to precalibrate the fixture loadings against their flow profiles and on the ability to utilize computer technology in the analysis of the profile data.

The measurements of peak air-flow rates in the vents produced values far below the values predicted from direct application of the theory presented in NBS Mono 31 [15], which is widely utilized in the

Table 4. *Summary of results: Comparison of trap performance for different combinations of open and closed ½-in×20-ft vents and 2-in manifold terminal, with various clean-water loads (one-story, slab-on-grade system [a])*

| Individual vents | | Manifold terminal | | Test load: fixture combinations/sequences [b c] | Material comprising lower 15 ft of building drain [d] | | Trap performance [f g] | Trap-seals reduced by more than 1 in [g] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All open | All closed | Open | Closed | | Cast iron | Plastic [d] | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory |
| X | | | X | W, 2, (B+J) | | X | S | | | | | |
| X | | X | | W, 2, (B+J) | X | | S | | | | | |
| X | | | X | All−L | X | | F | | | | | X |
| X | | | X | All−L | | X | S | | | | | |
| | X | — | — | All−L | | X | F | X | X | | | |
| X | | X | | All−L | | X | S | | | | | |
| X | | X | | All−L | X | | S | | | | | |
| X | | | X | All−W | X | | S | | | | | |
| X | | | X | All−W | | X | S | | | | | |
| | X | — | — | All−W | | X | F | X | | | | |
| X | | X | | All−W | | X | S | | | | | |
| X | | X | | All−W | X | | S | | | | | |
| X | | | X | All−J | X | | F | | | | | X |
| X | | | X | All−J | | X | S | | | | | |
| | X | — | — | All−J | | X | S | | | | | |
| X | | X | | All−J | | X | S | | | | | |
| X | | X | | All−J | X | | S | | | | | |
| X | | | X | All−K | X | | F | | | | | X |
| X | | | X | All−K | | X | F | | | | | X |
| | X | — | — | All−K | | X | S | | | | | |
| X | | X | | All−K | | X | S | | | | | |
| X | | X | | All−K | X | | S | | | | | |
| X | | | X | All−(J+K) [h] | X | | S | | | | | |
| X | | | X | All−(J+K) | | X | S | | | | | |
| | X | — | — | All−(J+K) | | X | F | X | | | | |
| X | | X | | All−(J+K) | | X | S | | | | | |
| X | | X | | All−(J+K) | X | | S | | | | | |
| X | | | X | All−B | X | | F | | | X | | X |
| X | | | X | All−B | | X | S | | | | | |
| | X | — | — | All−B | | X | F | | | X | | |
| X | | X | | All−B | | X | S | | | | | |
| X | | X | | All−B | X | | S | | | | | |
| X | | | X | All−C | X | | F | | | | | X |
| X | | | X | All−C | | X | S | | | | | |
| | X | — | — | All−C | | X | F | X | | | | |
| X | | X | | All−C | | X | S | | | | | |
| X | | X | | All−C | X | | S | | | | | |

[a] See figure 3.

[b] B = bathtub, C = automatic clothes washer, J = compartment of the kitchen sink not over trap and (K) = compartment of sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture. L = lavatory, W = water closet.

[c] Three types of symbols are used to designate the fixtures discharged to comprise a test load: (a) simultaneous discharge of group such as All = B+C+(J+K)+L+W, (b) partial simultaneous; All−(J+K) = all fixtures except the two-compartment kitchen sink, (c) sequential; W, 2, (B+J) = water closet followed by a 2-second pause followed by simultaneous discharge of the bathtub and compartment J of the kitchen sink.

[d] Building drain was nominal 3-in diam throughout, including the branch serving the sink and the clothes washer.

[e] Methyl methacrylate transparent plastic.

[f] F = Failed (at least one trap seal reduced by more than one inch).
S = Satisfactory, (no trap seal was reduced by more than one inch).

[g] Occurring in at least one of three successive trials. Water seals were replenished manually between trials.

[h] A single trap served the two-compartment sink (J+K).

TABLE 5. *Detailed results: Comparison of trap performance for different lengths of ½in vents, with various clean-water loads (one-story, slab-on-grade system[a])*

| Vent length (ft) | Load[b] application code | Test load: Combinations/sequences[c d] | Maximum trap seal reductions[b e f] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Clothes washer | Kitchen sink | Bathtub | Water closet | Lavatory |
| 50 | 1 | All−W; All−L; All−B; All−J; All−K; All−(J+K); All−C | 0.62 | 0.50 | 0.50 | 0.06 | 0.62 |
| 50 | 2 | (J+K);[f] C; W; L; B; All | .38 | .50 | .12 | .06 | .50 |
| 50 | 3 | All−W; All−L; All−B; All−(J+K); All−C; B, 2, W; C, 2, (J+K) | .75 | .62 | .56 | .16 | .62 |
| 40 | 1 | All−W; All−L; All−B; All−J; All−K; All−(J+K); All−C | .50 | .50 | .50 | .03 | .38 |
| 40 | 2 | (J+K); C; W; L; B; All | .25 | .12 | .12 | .19 | .38 |
| 40 | 3 | All−W; All−L; All−B; All−(J+K); All−C; B, 2, W; C, 2, (J+K) | .09 | .75 | .53 | .12 | .50 |
| 25 | 1 | All−W; All−L; All−B; All−J; All−K; All−(J+K); All−C | .31 | .62 | .31 | .00 | .25 |
| 25 | 2 | (J+K); C; W; L; B; All | .25 | .25 | .12 | .06 | .25 |
| 25 | 3 | All−W; All−L; All−B; All−(J+K); All−C; B, 2, W; C, 2, (J+K) | .38 | .50 | .38 | .06 | .38 |
| 10 | 1 | All−W; All−L; All−B; All−J; All−K; All−(J+K); All−C | .12 | .12 | .00 | .00 | .00 |
| 10 | 2 | (J+K); C; W; L; B; All; C, 2, (J+K) | .25 | .00 | .06 | .00 | .06 |
| 10 | 3 | All−W; All−L; All−B; All−(J+K); All−C; B, 2, W | .25 | .19 | .25 | .09 | .19 |
| 1 | 1 | All−W; All−L; All−B; All−J; All−K; All−(J+K); All−C | .00 | .00 | .00 | .00 | .00 |
| 1 | 2 | (J+K); C; W; L; B; All | .12 | .00 | .00 | .00 | .00 |
| 1 | 3 | All−W; All−L; All−B; All−(J+K); All−C; B, 2, W; C, 2, (J+K) | .06 | .00 | .12 | .06 | .06 |

[a] See figure 3. Nominal 3-in diam building drain throughout, including the branch serving the sink and clothes washer.

[b] The load applications/types of obervations are coded as follows:

(1) Three successive applications of load: trap seals replenished manually *before* each application; seal losses observed after each application.

(2) Four successive applications of load: beginning with full trap seals for first application, seals were *not* replenished between applications; seal losses observed *after each* application.

(3) A sufficient number of successive applications of load so as to yield for each trap at least four successive seal-loss values not greater than the first in this series of four: beginning with full trap seals for first application, seals were *not* replenished between applications; seal losses observed after each application.

[c] B = bathtub, C = automatic clothes washer, J = compartment of kitchen sink not over trap and K = compartment of sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture. L = lavatory, W = water closet.

[d] Three types of symbols are used to designate the fixtures discharged to comprise a test load: (a) simultaneous discharge of group such as All = B+C+(J+K)+L+W, (b) partial simultaneous; All−(J+K) = all fixtures except the two-compartment kitchen sink, (c) sequential; W, 2, (B+J) = water closet followed by a 2-second pause followed by simultaneous discharge of the bathtub and compartment J of the kitchen sink.

[e] Maximum occurring in one or more of the various listed loadings.

[f] A single trap served the two-compartment sink (J+K).

sizing of dry vents by plumbing codes. This can be explained on the basis that the vertical distances available for the water to fall before entering the building drain were so small in the one-story DWV system as to preclude the development of maximum water velocities and frictional drag, hence allowing substantial "slippage" between the water and the air in the vertical drains. This helps to explain why no trap-seal failures were observed for many loads with only one or two vents open.

### 2.4.4. Tests With Reduced-Size Vents and Manifold-Type Vent Terminal

#### 2.4.4.1. Test Procedure

Figure 3 shows in schematic form the one-story DWV system utilized for the tests described in sec-

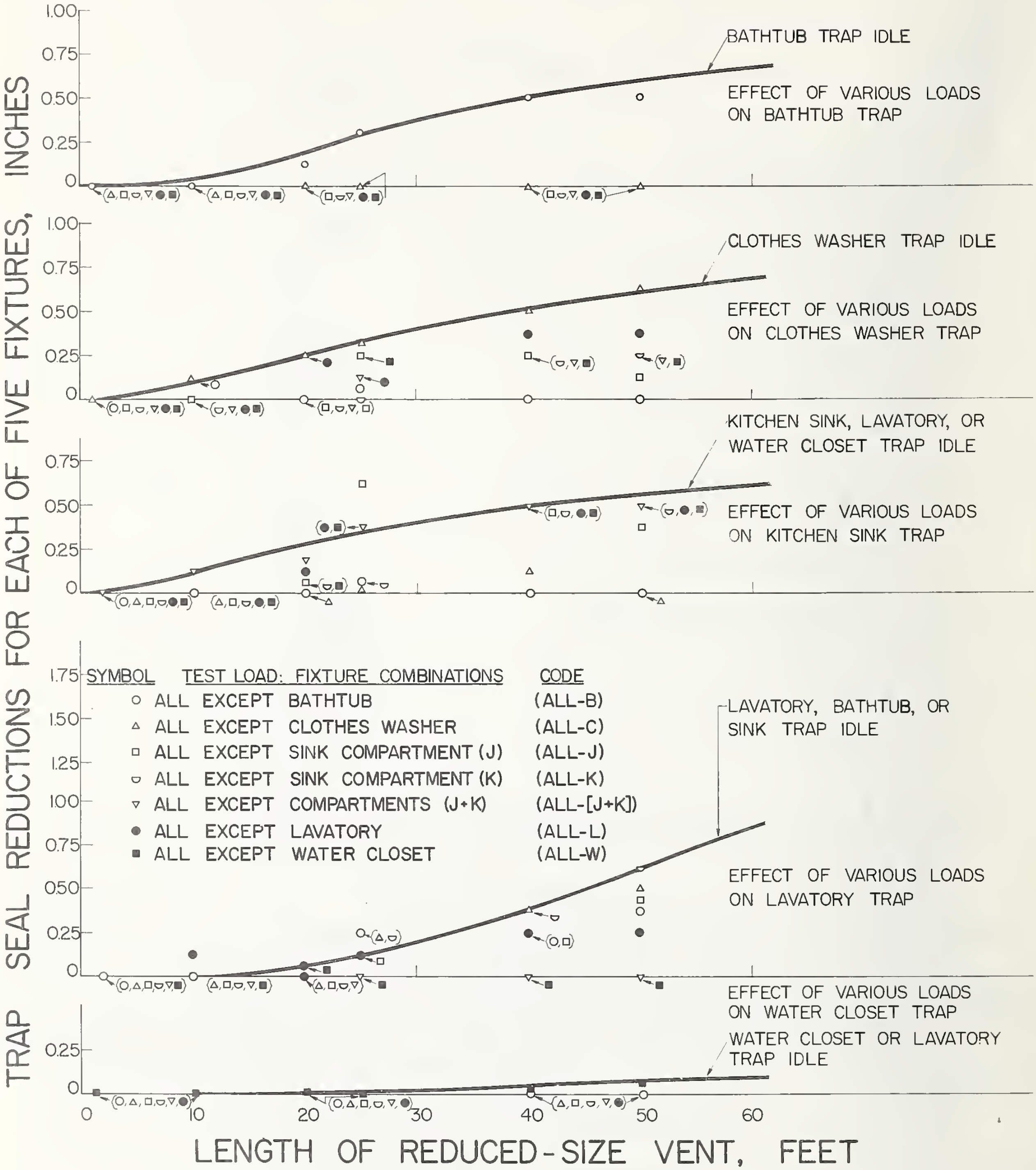


FIGURE 15. *Trap-seal reductions of all fixtures for various loads and for various lengths of ½-in vents (one-story, slab-on-grade system).*

tions 2.4.1 and 2.4.2, as modified to accommodate the tests with the reduced-size individual vents joined to a manifold vent terminal. The principal changes made in the test system were as follows:

1. The building drain branch serving the sink and clothes washer was increased to 3-in diam.

2. The individual vents were decreased to ½-in i.d. well above the flood-level rims of the fixtures served,

about 5 ft above floor level. The small-size flexible vent tubing used for these tests was coiled to accommodate the excess over that required to reach to the manifold vent terminal, as described later in section 3.

The test loads applied in these tests involved various combinations of fixtures discharged. One type of load comprised the simultaneous discharge of all fixtures except the particular one the trap seal of which was to be observed. These loads are indicated in tables 4 and 5 which also give the test results. The load code follows the same format as explained in section 2.3.

Three types of load effects were studied in these tests, as follows:

1. *Single-run effect.* Three successive applications of load, with replenishment of depleted trap seals before each application of the load. Trap-seal reductions were recorded after each application.

2. *Four-run cumulative effect.* Four successive applications of load, beginning with all trap seals full but without replenishment for the four runs. Cumulative trap-seal reductions were recorded after each application.

3. *Stabilized cumulative effect.* A sufficient number of successive applications of load, beginning with all trap seals full but without replenishment, so as to yield for all traps at least four successive trap-seal reduction values not greater than the first in this series of four. Stabilized cumulative trap-seal reductions were recorded at the end of the series of runs.

Some tests were run with the vent manifold closed to simulate effects of complete closure by frost or other environmental conditions, while at the same time slightly restricting the flow in the building drain to cause it to flow at increased depth, as might occur in service due to an obstruction or gradual fouling.

Other tests were run with the lower 15 ft of the cast-iron building drain replaced with smooth, transparent plastic of the same nominal 3-in diam. These tests were intended to show possible effects of using a building drain material smoother than cast iron. These tests were run first with the individual vents closed off and then with the vents and manifold terminal open.

#### 2.4.4.2 Results

The principal results obtained with the tests on the one-story, slab-on-grade DWV system with various lengths of ½-in i.d. tubing instead of the usual code sizes of vents are summarized in tables 4 and 5. It is important to remember that the results shown in table 5 are the most severe results observed with the several indicated loads with the entire building drain 3 inches in diameter; actually the seal reductions for most of the idle traps and for many of the loads were less than the maximum value listed for the most-severely affected trap for each group of tests involving several different loads. Figure 15 shows the results of the observations of trap-seal changes for all the fixtures as affected by length of ½-in vents, for various loads comparing the simultaneous discharcge of all fixtures

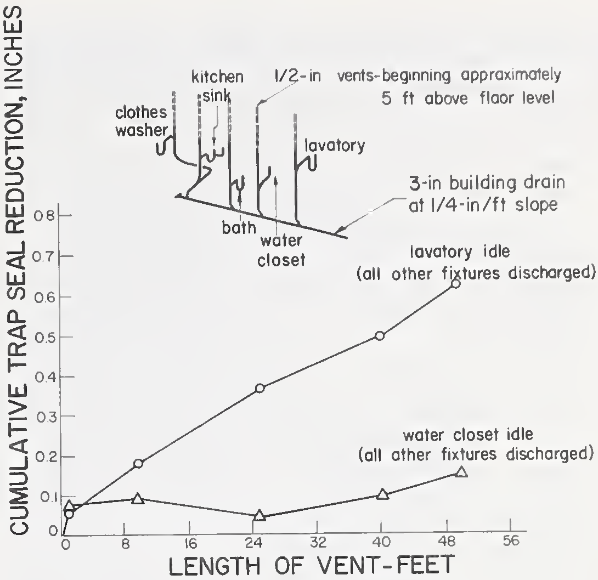


FIGURE 16. *Cumulative reductions of idle water closet or lavatory trap seals, for various lengths of ½-in vents (one-story, slab-on-grade system, all vents open).*

except one. The data are the averages of trap-seal reductions for three runs where traps were replenished after each run. An upper-envelope curve encompasses the plotted points representing the idle trap. Figure 16 shows cumulative trap-seal reduction for the water closet and lavatory traps with all other fixtures discharged in each case. The data of tables 4 and 5, and of figures 15 and 16, show no trap-seal failures with any of the loads applied with the reduced-size vents and vent manifold open.

In table 4, satisfactory trap performance was observed in nine of fifteen tests with the manifold terminal closed, and in three of seven tests with all the vents individually closed. In all the tests with the reduced-size vents open and the manifold terminal open, satisfactory trap performance was observed.

Load W,2,(B+J) with ½ in diam vents 20 ft long produced the following data:

| Conditions | Stabilized cumulative trap-seal reduction, maximum in any trap |
|---|---|
| Building drain 3-in diam cast iron throughout, manifold vent terminal closed | 0.4 in (clothes washer trap) |
| Lower 15 ft of building drain replaced with transparent plastic, manifold vent terminal open to atmosphere | 0.2 in (clothes washer trap) |

These data show that the 3-fixture load used did not produce trap-seal failure, even with the vent terminal closed. Comparison of the trap-seal reduction of 0.4 in

shown above for the closed-terminal condition with the data of table 4, for somewhat similar loads with ½-in vents 25-ft long and open terminal, suggests that closing the terminal probably had a relatively minor effect.

TABLE 6. *Effect of size of building drain branch serving clothes washer and sink, with all vents closed (one-story, slab-on-grade system*[a])

| Fixtures comprising load | Trap observed | Trap-seal reduction | |
|---|---|---|---|
| | | 2-in drain in | 3-in drain in |
| C | Sink | 0.16 | 0.00 |
| J | Clothes washer | 2.00 | 0.19 |
| K | Clothes washer | 0.44 | .06 |
| J+K | Clothes washer | 1.75 | .62 |

[a] See figures 2 and 3 showing test system.

The data of table 6 for all vents closed shows the advantages of increasing to 3 in the size of the building drain branch serving the sink and clothes washer. For the test shown, the air relief with the 3-in drain apparently occurred via the air space over the water on the 3-in building drain system.

The results of tests made with the lower 15-ft section of the 3-in cast iron main building drain replaced with 3-in plastic pipe showed a striking improvement over the results with the entire building drain of 3-in cast iron. In both cases the test system utilized ½-in vents connecting to the manifold terminal, but the terminal was closed. The comparison is presented for the case of the closed terminal rather than with it open, because any effects of the building drain on effectiveness of the venting are more likely to be detected with the vents closed or restricted than with them fully open. So these comparisons are made using data from test conditions not recommended as operating conditions, i.e., vent terminal closed—a very critical test of the functional capability of any DWV system. The concept of reduced-size venting is based on the premise that each DWV system will be vented to the atmosphere through one or more adequately sized terminal(s). Hence, in the comparison presented here, some failures would be expected regardless of the condition of the building drain.

Twenty-one tests were conducted for each condition involving seven different loads. Even though the vent manifold terminal was completely closed, trap-seal reductions did not exceed 1 inch in six of the tests with the cast-iron reach, and did not exceed 1 inch in twenty of the tests with the plastic reach. Probably this is attributable to the fact that the lesser hydraulic resistance of the plastic reach might have been expected to have reduced the peak depth of water in that section of the drain, thus allowing more effective pneumatic relief over the water surface than when the cast-iron reach was employed.

Comparisons of trap-seal reductions with the plastic drain, with the individual vents closed off and with ½-in vents 20-ft long connected to the manifold terminal open to the atmosphere showed trap-seal reductions of one inch or less in fourteen of twenty-one tests involving seven loading with all of the vents individually closed, and *no reductions exceeding one inch* for the same tests with the ½-in x 20-ft individual vents open and connected to the manifold terminal which was open to the atmosphere.

Comparable data with the entire building drain of 3-in cast iron, obtained from the same tests and loadings as above, showed trap-seal reductions of 1 inch or less in five of the twenty-one tests with the terminal closed, and no reductions exceeding 1 inch with it open.

A pass-fail summary of the test results with the entire building drain 3-in diam (either all cast iron or part plastic), taking into account open or closed condition for the individual ½-in diam x 20-ft long vents and the 2-in manifold vent terminal, is shown in table 4.

#### 2.4.4.3. Discussion

The most important findings are shown in table 5. These data show that there was not a single trap-seal failure in the many tests summarized in the table, with the ½-in diam individual vents as long as 50 ft. Figures 15 and 16 show that vent length affected idle trap-seal reductions, as was expected. No attempt was made to define equations for these curves.

Figure 15 shows that although two or more traps suffered some degree of seal reduction in some of the loads comprising the discharge of all fixtures except one, the idle trap was affected the most, as had been expected for the particular DWV system used for these tests. However, had the design utilized long trap arms or steeply sloped trap arms, self-siphonage might have been expected and this could have produced trap-seal reductions in active traps exceeding those in the idle traps. Possibly other conditions in complex systems comprising some poorly designed components could exhibit induced siphonage in active traps exceeding that in the idle traps. This suggests that the organization of data in a format similar to figure 15 would be helpful in interpreting the data. The particular form of the envelope curves shown in figure 15 is empirical; however, experimentation and analysis designed to study this factor might provide a mathematical model to define curves of this type.

Review of the data of tables 4, 5, and 6 indicates the following:

1. The use of smooth materials in combination with adequately sized building-drain system components tended to prevent excessive water depths in the building drain, and hence contributed to the maintenance of a continuous air space and pressure relief above the water during peak-loading periods.

2. Adequate venting was accomplished with a number of loads even when the individual vents or the common vent terminal were closed, with a 3-in building drain beginning at the fixture farthest upstream, especially when a part of the drain was comprised of smooth material.

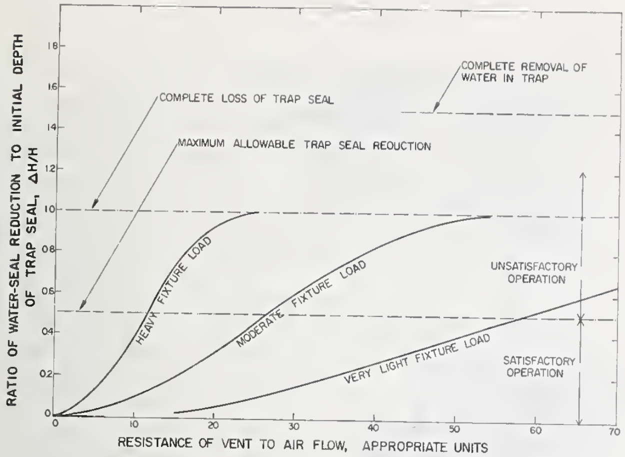


FIGURE 17. *Conceptual illustration of relative trap-seal reductions as affected by resistance of vent and magnitude of load.*

### 2.5. Summary

The tests made utilizing several variations of the one-bath, slab-on-grade DWV system provided strong support for the hypothesis that with competent engineering design and evaluation, many DWV systems in one-story houses could be adequately vented with reduced-size vents. This was evidenced by the fact that sufficient air relief occurred to protect trap seals with vents much smaller in diameter than customarily used. Evidence was obtained that a considerable amount of air exchange occurred within the DWV network when the vents were connected to a manifold that was closed to the atmosphere at its terminal.

The results of tests made with loads that produced a full or nearly full condition in the main building drain or in the branch serving the kitchen/laundry areas showed that complete closure of some or all of the vents tended to produce significantly greater trap-seal reductions than if the drains flowed less full with the same loads (e.g., a smoother pipe or a larger-size pipe).

The data showing apparent water depth in the building drain as a function of time provided significant support to the hypothesis that the monitoring of water depth in a horizontal drain serving a number of fixtures may provide an economical way of identifying load patterns in terms of composition and time distribution while at the same time determining drain capacities with intermittent, short duration flow.

The data with successive loads without refilling idle traps showed that generally maximum seal reduction in the idle traps was closely approached in three or four occurrences of the load.

Little evidence of a meaningful relationship between trap-seal reduction or retention and vent pressure excursion was found, other than that large trap-seal reductions were generally associated with large pressure excursions.

Review of the various data obtained provided a basis for figure 17, a conceptual illustration of the effects of vent resistance and magnitude of load on trap performance.

The forms of the curves have not been precisely defined, but the broad trends and effects observed can be related to this illustration. Vent resistance is a function of diameter, length, roughness, and configuration. Load is a function largely of hydraulic discharge rate, DWV system dimensions and configuration, and time and spatial distribution of the elements of the hydraulic discharge.

Various views have been expressed as to the upper limit for relative trap-seal reduction, ΔH/H, that should be accepted. A relative reduction of 0.50 has been shown here for illustrative purposes. The nature of the function in the zone between "trap seal reduced to zero" and "complete removal of water in trap" were not studied in this investigation, and it does not seem purposeful to perform research in this area (zone) that has little practical significance.

Although the results obtained were significant, the characteristics of the simple one-story system used for the first part of the investigation severely limited the application of the results in predicting performance in other types of systems. For example, how would trap performance be affected by the greater stack heights in systems with two, three, or more branch intervals? Would trap performance with a reduced-size vent be significantly different with common venting or with wet venting instead of individual venting? How might the results be extrapolated to predict performance with more complex configurations of DWV piping and more and different types of fixtures? Consideration of these questions led to the decision to undertake a second series of tests with a split-level system with fourteen fixtures, including three additional fixture types of fixtures or appliances.

## 3. Venting Studies Conducted on a Test Set-up Representing a Complete DWV System for a Three-Level (Two Stories and Basement), Three-Bath House

### 3.1. Purpose and Scope

The test plan adopted for the study required trials with a DWV system having more than one branch interval of connected plumbing fixtures. It was expected that the greater height and complexity of such a system might impose greater air demands and offer more opportunity for air recirculation within the sys-

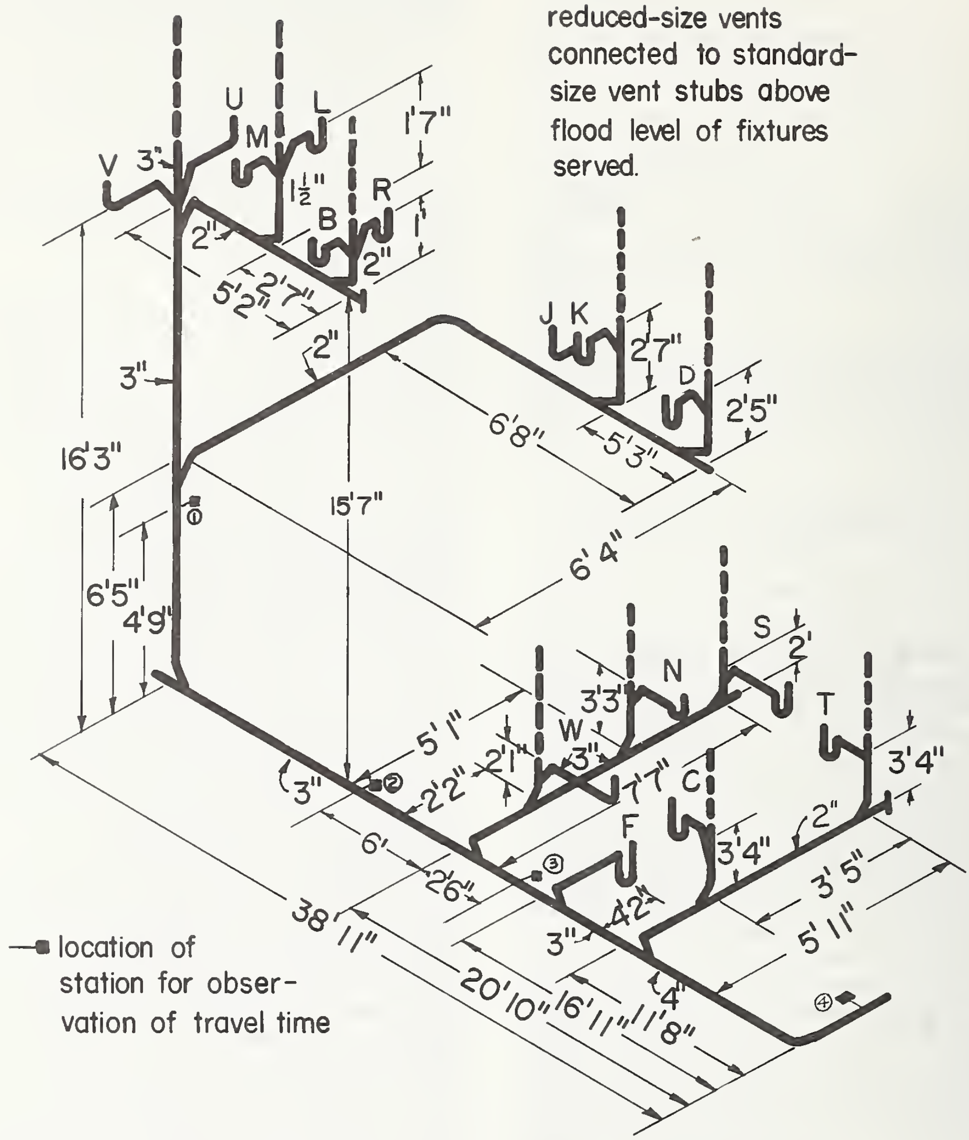


Figure 18. *Split-level DWV test system, showing plumbing dimensions and locations of measurement stations.*

tem than the one-story, slab-on-grade system first studied, and hence, would be purposeful for testing the hypothesis that reduced-size vents might be successfully used in multi-story systems.

Other reasons for selecting the particular system used included:

(a) A greater number of fixtures and fixture types were used than for the one-story system.

(b) The utilization of common vents instead of individual venting provided the opportunity for examining the performance of this popular type of venting with reduced sizes.

These characteristics, typical of modern homes, were expected to place greater demands on the vents than in the case of the one-story system. The system used for the tests, as shown in figure 18, was selected in consultation with the NAHB staff.

Three important types of measurements were made. Fixtures not calibrated for hydraulic characteristics in connection with the tests on the one-story system were calibrated, measurements were made of travel times and apparent velocities in the building drain resulting from several fixture loadings, and trap performance (trap-seal retention and detergent blow-back) was studied with various test loads, dimensions and arrangements of vents.

### 3.2 Description of DWV System

The test system, representing a complete DWV system for a three-level (two stories and basement),

three-bath house, is shown in schematic form in figure 18.

To simplify the experimental work the vents were not interconnected as would normally be done in the field, but were terminated separately. This condition may have provided a somewhat greater degree of venting than if they had been interconnected.

All drain piping which would normally be below grade was fabricated of service weight cast-iron pipe, as were also the 3-in soil stacks and 3-in soil vents. The cast-iron soil piping and fittings were of hub type joined with neoprene gaskets; however, in some instances where special fittings were not available, oakum-pitch joints were made. All of the 1½- and 2-in vents and all of the drain branches that were installed in an above-grade location were fabricated of Schedule 40, galvanized steel pipe and appropriate recessed, screwed, cast-iron drainage fittings. For most of the work the building drain was 3-in diam from its origin downstream to the point of connection to the basement laundry group, and beyond this point it was enlarged to 4 in. Near the end of the program, the 4-in reach was extended upstream to the basement bathroom group. This short reach of building drain between the basement bathroom group and the basement laundry group served three water closets in addition to other fixtures as shown in figure 18.

The system was designed to discharge into the laboratory building drain through an air gap. Such separation assured atmospheric pressure at the end of the experimental drain.

The two showers (R and S) were simulated by means of 2-in cast-iron soil pipe "P" traps. The floor drain (F) was represented by a 3-in cast-iron soil pipe "P" trap. A means was provided for introducing water to replenish any trap-seal reduction in these traps, none of which were involved in creating any of the test loads.

The two back-to-back water closets (U and V) were joined to the 3-in soil stack by 4″ x 6″ x 16″ closet bends and 3″ x 4″ double Washington combination wye-and-eighth bends. The water closet on the lower level (W) was joined to the 3-in soil stack by a 4″ x 3″ reducing closet bend and a 3-in combination wye-and-eighth bend. As shown in figure 18, the other fixtures included a bathtub (B) installed back-to-back with a shower (R); two back-to-back lavatories (L and M) on the upper level and one on the basement level (N); and a two-compartment kitchen sink (J and K) with food-waste disposal unit, and a dishwasher (D) on the intermediate level. The dishwasher was installed with its own trap and vent. The laundry fixtures consisted of a concrete laundry tub (T) and automatic clothes washer (C), each installed with a separate trap and vent. The clothes washer discharged first into a 2-in standpipe, then through a screwed, cast-iron drainage "P" trap into a 2-in vertical waste pipe. The water supply for the test system consisted of lengths of ½-in i.d. rubber garden hose terminating at the fixtures at one end and at a pressure-reducing station manifold at the other end, adjusted to maintain a supply pressure of approx 50 psi.

The complete DWV system was air tested with a positive pressure of 2-in of water column to assure a tight system.

## 3.3. Approach to Measurement and Test Control

### 3.3.1. Measurement

The hydraulic calibrations of the fixtures determined as described in section 2.3.1 for the one-story system were assumed valid for the split-level system in all instances where the same fixture-drain fittings and trap-arm configurations were used. The laundry tub and the dishwasher had not been used in the one-story system. Neither had the food-waste disposal unit been used with the sink. Two of these three fixtures were calibrated in a simple fashion as stated in section 3.5.1.

The approach to measurement of the time for water discharged from the fixtures to reach particular stations in the building drain (see fig. 18) was through the use of stop watch and electric probes inserted through the crown of the drain and extending nearly to the invert. The probes were connected to a power supply, a microammeter, and a hand-operated multi-station switch. This principle is illustrated in figure 5 (A and B), as used for detection of water level in the bathtub trap in the one-story system.

The approach to detection of trap-seal reduction in the split-level system also utilized the electric probe technique. In order to facilitate the display of results at a central station, an indicator system was fabricated to permit advancing or retracting the probes so as to determine contact with the water surface, and to permit reading the reductions on an appropriate scale, all from the central station. This is shown schematically in figure 19.

### 3.3.2. Test-Load Selection, Designation, and Application

#### 3.3.2.1. Test-Load Selection

Test loads were selected to yield a range of composite discharge rates. This approach, a somewhat arbitrary one, was similar to that described in section 2.3.2 for the one-story system. The general idea was to consider the DWV system in successively more complex assemblies, starting with individual fixtures, proceeding then to consider the two or more fixtures served by common fixture branches or vertical waste pipes, then to consider the group of fixtures in a particular room arrangement and the back-to-back combinations of two room-groups, and finally to consider all the fixtures on a particular stack and on the system as a whole as a composite group. The intention was to select, in this way, a reasonable test load for testing the drains and vents of each particular group being considered. Reference to mathematical guides presented recently [12] indicates that a number of the loads used in these tests were greater than might be expected under normal service conditions for a DWV system like the one represented by the split-level test system.

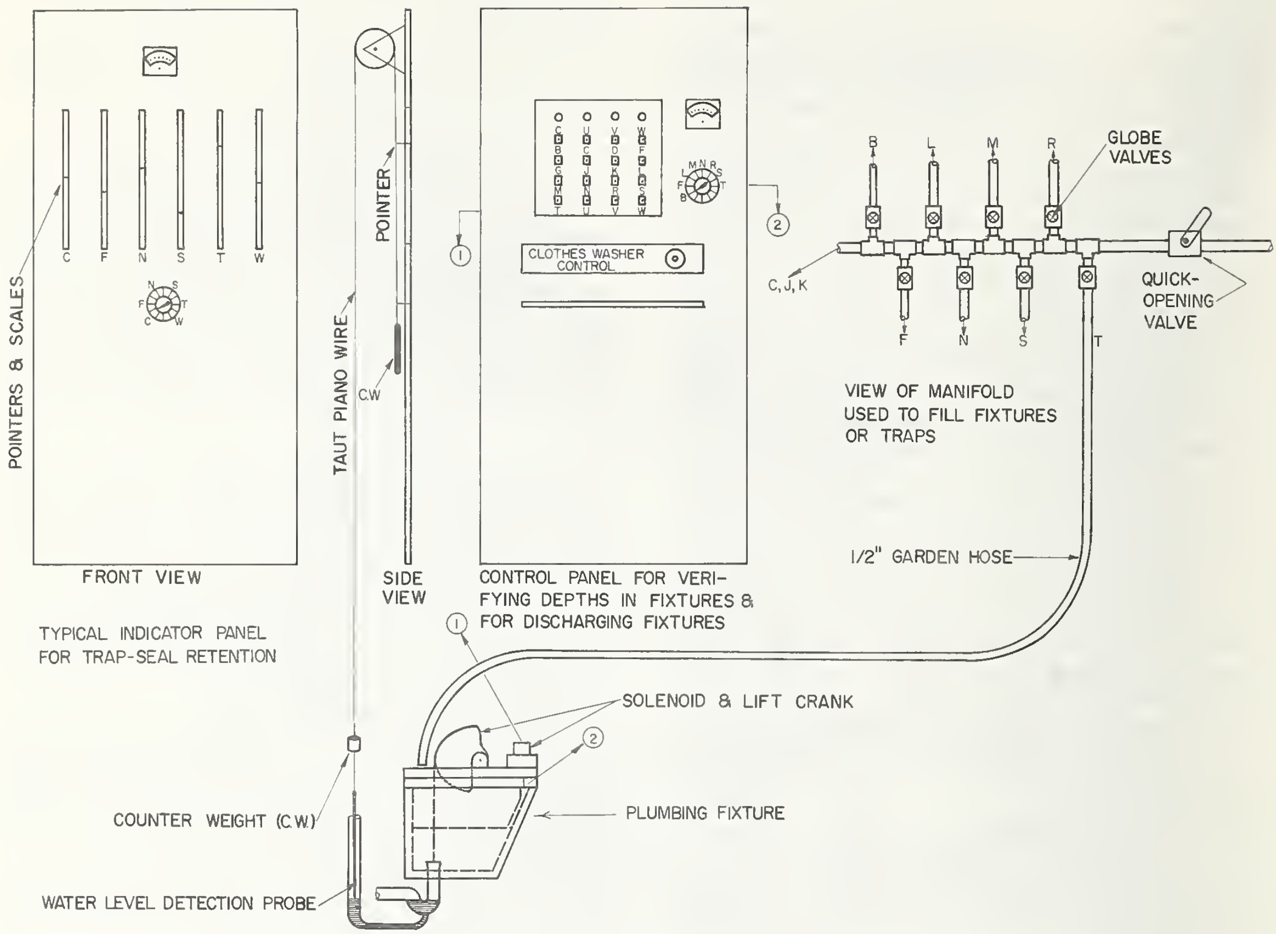


FIGURE 19. *Method for filling and discharging fixtures, and for detecting trap-seal reductions (split-level system).*

Because of the lack of load data for plumbing, particularly as to distribution of fixture operation by time and fixture type, test load selection is likely to remain somewhat arbitrary. Better load data is needed to provide the basis for the kind of mathematical guides required to standardize the selection of loads for testing DWV and water supply systems, following the qualitative approach described above.

#### 3.3.2.2. Test-Load Designation

To simplify and shorten the descriptions of fixture loadings, a code similar to that used with the one-story, slab-on-grade system has been used in presenting and discussing the findings. The letter symbols used are defined in the footnotes to the tables of results, and are shown on figure 18.

#### 3.3.2.3. Test-Load Application

In order to minimize the amount of manual work required to fill and discharge fixtures, various electrical controls were added. This provided the means by which all fixtures involved in creating the test loads could be filled and discharged remotely from a central station by one operator.

Figure 19 indicates schematically the methods used. Switches were provided on the control panel to perform the following functions:

1. Selection of fixtures to be filled.
2. Starting and stopping of the filling operation.
3. Selection of fixtures to be discharged.
4. Initiation of discharges from fixtures according to predetermined, simultaneous or time-sequence program.

Electric solenoids were utilized to pull the drain plugs and flush the water closets in the same manner as described in section 2.3.2.3 for the one-story system. Also, the initiation of the clothes washer discharge was accomplished as described in section 2.3.2.3.

A light indicator was provided, on the control panel for each fixture involved in the test load, that signalled when the fixture was filled to a predetermined depth. A timer was provided as an aid in the manual operation of the fixture discharge switches according to a time-sequence loading program.

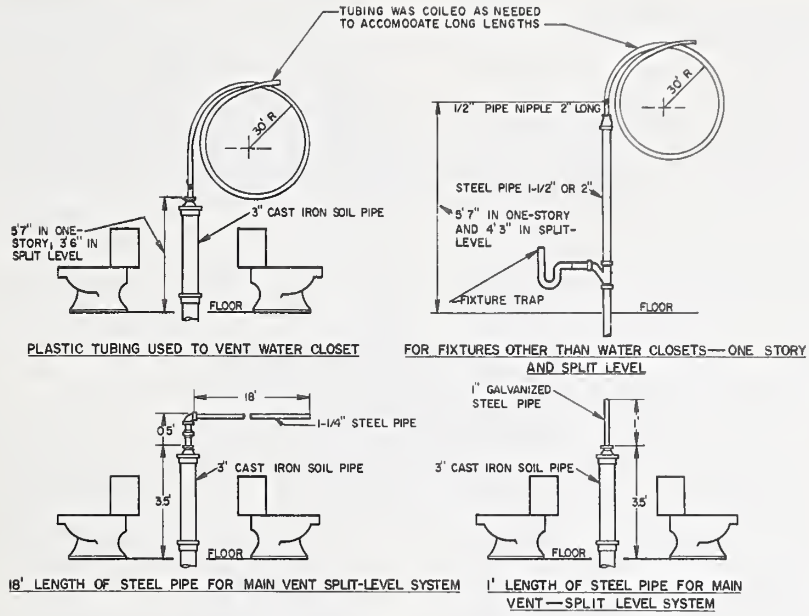


FIGURE 20. *Methods for reducing vent sizes above fixture flood-level rim.*

TABLE 7. *Venting arrangements used in tests on split-level 3-bath system*

| Code | Main vent | | | | All other vents | | | |
|---|---|---|---|---|---|---|---|---|
| | Diam *in* | Length *ft* | Open | Closed | Diam *in* | Length *ft* | Open | Closed |
| 1 | 1¼ | 18 | x | | 1½ [a] | 5 | x | |
| 2 | 1¼ | 18 | x | | ½ | 25 | x | |
| 3 | 1 | 1 | x | | ½ | 1 | x | |
| 4 | 1 | 1 | x | | ½ | 25 | x | |
| 5[a] | ½ | 1 | x | | ½ | 1 | x | |
| 5[b] | ½ | 1 | x [c] | | ½ | 1 | x [c] | |
| 6 | ½ | 25 | x | | ½ | 25 | x | |
| 7 | ½ | 50 | x | | ½ | 50 | x | |
| 8 | ½ | 50 | | x [b] | ½ | 50 | | x [b] |

[a] Vent to W was 3-in diam × approx 4-ft long, reduced to 2½-in diam at terminal by orifice.
[b] Closed by sealing terminals. Internal volume of each vent was approx ½ gal.
[c] Vents to kitchen sink and dishwashing machine closed.

With these provisions for remote application of selected hydraulic loads by a single operator at a central station, the testing was greatly facilitated.

### 3.4. Test Procedure

The procedure for determination of times for the water discharged from the fixtures to reach selected stations involved use of the electric-probe approach described in section 3.3.1. Loads were repeated as determinations were made at the several stations in the building drain shown in figure 18.

The procedure for studying trap performance involved the application of a variety of test loads, some of which included detergents with either hot or cold water. The quantities and types of detergents used, as well as other details, are shown with the test results.

For the purpose of comparing trap performance with clean water and with included solids, cellulose sponge pieces were used. A sponge brick was cut into thirds so that each piece was approximately 4½-in long and 1¼- x 1¼-in in cross section. Tests were made utilizing one, two, or three pieces in one toilet, flushed alone or with other fixtures. The water closet did not flush effectively with more than three pieces of sponge. This is a convenient way to simulate human feces for the purpose of hydraulic tests, but because they do not disintegrate under the action of the water they may represent a more severe load than human feces. Tests were made with several different venting

arrangements in which the standard-size vent stubs shown in figure 18 were extended with pipe or tubing in the manner shown in figure 20.

The various combinations of sizes and lengths of vents either open or closed are designated by code number as shown in table 7. Trap-seal reductions were determined using the approach described in section 3.3.1. For the test loads involving unusually severe loads, visual observations of the lower fixtures were made for evidence of blow-back.

As to test statistics, the general procedure was to obtain all measurements in triplicate, with trap seals refilled before each run. In the process of reducing the volume of the data for compact presentation in this paper, some of the measurements were classified as S (satisfactory) or F (fail), corresponding to a trap-seal reduction of 1.0 in or less or of more than 1.0 in, respectively. For the purposes of this classification the replicate measurements were reviewed and the classification S or F made on the basis of the greatest single trap-seal reduction recorded in the three runs. It is believed this approach with the data obtained tends to provide interpretations comparable to those with data on cumulative trap-seal reductions, with traps not refilled before each run, as described in section 2.4 for the one-story, slab-on-grade system. The method used pertaining to each specific group of data is indicated on the appropriate table or figure.

## 3.5. Result and Discussion

### 3.5.1. Fixture Calibrations

The active fixtures for the three level system consisted of three water closets (U,V,W), three lavatories (L,M,N), one two-compartment kitchen sink (J,K), one bathtub (B), one automatic clothes washer (C), one automatic dishwasher (D), and one laundry tub (T).

The floor drain (F) and the two showers (R,S) were roughed-in for drainage but not for water supply. Water to refill the trap seals was supplied as needed. The food waste disposal unit (G) was attached to the kitchen sink and carried the same discharge load as the sink compartment.

Only the dishwasher and laundry tub were calibrated since the two additional water closets and lavatories were identical with the ones used in the one-story facility. By observing the level to which the automatic operation of the dishwasher would fill the machine, with a supply pressure of 50 psi, it was established that 2.38 gal of water was used in both the wash and the rinse cycles. The time required to discharge 2.38 gal was 50.2 s ±0.6 resulting in a rate of discharge of 2.85 gpm.

The laundry tub when filled to 7½ in above the discharge orifice contained 11.2 gal. It was determined that the average flow rate during the discharge period was 14.0 gpm.

The effect on the flow rate from the kitchen sink compartment with the food waste disposal unit installed was not determined.

### 3.5.2. Travel Times and Apparent Velocities for Hydraulic Loads

Table 8 and figures 21 and 22 show the results of measurements of the travel time for the flow of water in the DWV system from the time of discharge to the time of arrival at the measuring station following the procedure described in section 3.4 and illustrated in figure 16.

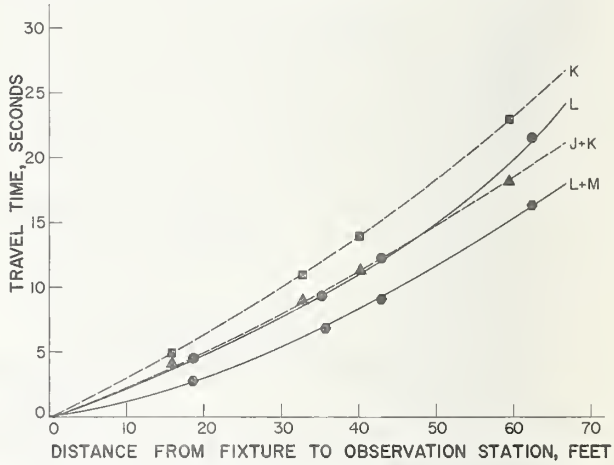


FIGURE 21. *Travel times for water to reach measurement stations in building drain: effect of increasing discharge rate (split-level system)*

Load Key

| Symbols | Fixture(s) discharged |
|---|---|
| J+K | Both compartments of kitchen sink |
| K | Sink compartment No. 2 (directly over food-waste disposal unit) |
| L | Top-story lavatory |
| L+M | Top-story lavatories back to back |

In figure 21 the pair of solid curves compare the travel time for the discharge from the lavatory (L) with that for the simultaneous discharge of the back-to-back lavatories (L+M). This comparison is purposeful since the two lavatories have essentially identical and/or common drain piping. The curves drawn with dashes compare the travel time for one compartment (K) of the kitchen sink with the travel time of the discharge from both compartments (J+K). The drains from the two compartments have a common trap.

Doubling the discharge rate by simultaneously discharging both of the back-to-back lavatories resulted in a reduction of travel time for the lavatories of 24 percent. An approximate doubling of the rate discharged through the sink trap (by discharging J+K instead of K) reduced travel time by 20 percent.

In figure 22 a comparison is made of the travel times for the discharge from the water closet (U) with that for the simultaneous discharge of the back-to-back water closets (U+V). Here also the results showed that doubling the discharge rate reduced the travel time substantially (27%).

TABLE 8. *Travel time for fixture discharges to reach selected stations in drainage system* [a]

| Fixtures discharged [b] [c] | Distance from fixture to Sta. 1, feet | Elapsed time, seconds | Apparent water velocity, fixture to Sta. 1, fps | Distance from fixture to Sta. 2, feet | Elapsed time, seconds | Time from Sta. 1 to Sta. 2 (16.8 ft), seconds | Apparent water velocity, Sta. 1 to Sta. 2, fps | Distance from fixture to Sta. 3, feet | Elapsed time, seconds | Time from Sta. 2 to Sta. 3 (7.4 ft), seconds | Apparent water velocity, Sta. 2 to Sta. 3, fps | Distance from fixture to Sta. 4, feet | Elapsed time, seconds | Time from Sta. 3 to Sta. 4 (19.4 ft), seconds | Apparent water velocity, Sta. 3 to Sta. 4, fps | Time, from Sta. 2 to Sta. 4 (26.8 ft), seconds | Apparent water velocity, Sta. 2 to Sta. 4, fps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U | 13.5 | 5.0 | 2.70 | 30.33 | 10.0 | 5.0 | 3.36 | 37.75 | 12.3 | 2.3 | 3.22 | 57.16 | 17.3 | 5.0 | 3.88 | 7.3 | 3.67 |
| V | 13.5 | 5.0 | 2.70 | 30.33 | 10.0 | 5.0 | 3.36 | 37.75 | 12.0 | 2.0 | 3.71 | 57.16 | 17.0 | 5.0 | 3.88 | 7.0 | 3.83 |
| L | 18.66 | 4.6 | 4.05 | 35.50 | 9.3 | 4.7 | 3.58 | 42.91 | 12.3 | 3.0 | 2.47 | 62.33 | 21.6 | 9.3 | 2.08 | 12.3 | 2.16 |
| B | 18.0 | 4.6 | 3.91 | 34.83 | 11.0 | 6.4 | 2.62 | 42.25 | 14.0 | 3.0 | 2.47 | 61.66 | 22.6 | 8.6 | 2.25 | 11.6 | 2.31 |
| J | 15.91 | 5.3 | 3.00 | 32.75 | 11.6 | 6.3 | 2.67 | 40.16 | 16.0 | 4.4 | 1.68 | 59.58 | 23.6 | 7.6 | 2.55 | 12.0 | 2.23 |
| J*[d] | 15.91 | 7.0 | 2.27 | 32.75 | 12.3 | 5.3 | 3.17 | 40.16 | 17.0 | 4.7 | 1.57 | 59.58 | 27.0 | 10.0 | 1.94 | 14.7 | 1.82 |
| K | 15.91 | 5.0 | 3.18 | 32.75 | 11.0 | 6.0 | 2.80 | 40.16 | 14.0 | 3.0 | 2.47 | 59.58 | 23.0 | 9.0 | 2.15 | 12.0 | 2.23 |
| K* | 15.91 | 5.0 | 3.18 | 32.75 | 11.0 | 6.0 | 2.80 | 40.16 | 14.0 | 3.0 | 2.47 | 59.58 | 23.0 | 9.0 | 2.15 | 12.0 | 2.23 |
| D | 19.50 | 9.0 | 2.16 | 36.33 | 17.6 | 8.6 | 1.95 | 43.75 | ([g]) | — | — | 63.16 | 31.6 | — | — | 14.0 | 1.91 |
| W | ([e]) | — | — | — | — | — | — | 7.66 | 5.2 | — | 1.47 | 27.08 | 13.5 | 8.3 | 2.33 | — | — |
| N | — | — | — | — | — | — | — | 11.75 | 4.5 | — | 2.61 | 31.16 | 13.0 | 8.5 | 2.28 | — | — |
| T | — | — | — | — | — | — | — | — | — | — | — | 17.50 | 10.0 | — | 1.75 | — | — |
| C | — | — | — | — | — | — | — | — | — | — | — | 20.91 | 12.3 | — | 1.70 | — | — |
| U+V | 13.5 | 5.0 | 2.70 | 30.33 | 8.0 | 3.0 | 5.61 | 37.75 | 10.0 | 2.0 | 3.71 | 57.16 | 12.8 | 2.8 | 6.93 | 4.8 | 5.58 |
| L+M | 18.66 | 2.7 | 6.91 | 35.50 | 6.8 | 4.1 | 4.10 | 42.91 | 9.0 | 2.2 | 3.36 | 62.33 | 16.3 | 7.3 | 2.66 | 9.5 | 2.82 |
| L+U | ([f]) | 3.8 | (*) | (*) | 7.8 | 4.0 | (*) | (*) | 9.8 | 2.0 | (*) | (*) | 15.8 | 6.0 | — | 8.0 | — |
| B+V | (*) | 4.2 | (*) | (*) | 8.2 | 4.0 | (*) | (*) | 9.8 | 1.6 | (*) | (*) | 16.9 | 7.1 | — | 8.7 | — |
| B+L+M+U+V | (*) | 2.6 | (*) | (*) | 6.3 | 3.7 | (*) | (*) | 7.5 | 1.2 | (*) | (*) | 12.5 | 5.0 | — | 6.2 | — |
| J+K | 15.91 | 4.3 | 3.70 | 32.75 | 8.9 | 4.6 | 3.66 | 40.16 | 11.3 | 2.4 | 3.08 | 59.58 | 18.2 | 6.9 | 2.81 | 9.3 | 2.88 |
| (J+K)* | 15.91 | 4.0 | 3.97 | 32.75 | 9.5 | 5.5 | 3.06 | 40.16 | 12.2 | 2.7 | 2.74 | 59.58 | 21.5 | 9.3 | 2.08 | 12.0 | 2.23 |
| C+T | — | — | — | — | — | — | — | — | — | — | — | (*) | 8.2 | — | (*) | — | (*) |
| (D+J+K), 2, (B+L+M+U+V) | (*) | 3.0 | (*) | (*) | 5.5 | 2.5 | (*) | (*) | 7.8 | 2.3 | (*) | (*) | 14.1 | 6.3 | (*) | 8.6 | (*) |

[a] See figure 18 showing test system.

[b] B = bathtub, C = automatic clotheswasher, D = dishwasher, J = compartment of the kitchen sink not over trap and K = compartment of the sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture. L and M are back-to-back lavatories on the top level, N is a lavatory on the bottom level, T = concrete laundry tub, U and V are back-to-back water closets on the top level and W is a water closet on the bottom level.

[c] Three types of symbols are used to designate the manner in which fixtures were discharged[i] (a) simultaneous discharge of group such as All = B+C+D+(J+K)+L+M+N+T+U+V+W, (b) partial simultaneous; All − (J+K) = all fixtures except the two-compartment kitchen sink, (c) sequential: W, 2, (B+J) = water closet W followed by a 2-second pause followed by simultaneous discharge of the bathtub and compartment J of the kitchen sink.

[d] For the J*, K* and (J+K)* loads the food-waste disposal unit was operating.

[e] Dashes indicate that information is not applicable.

[f] Asterisks indicate that where other than back-to-back combinations of fixtures are involved, a common distance measurement is not definable.

[g] This information was not obtained.

Comparison of these reductions in travel time with predictions from continuous-flow theory, i.e., the Manning formula and the basic hydraulic elements for circular sewers flowing partially filled [16], indicates that the values obtained, although greater than predicted, are explainable on the basis of the attenuation of short duration and/or "peaky" profile discharges. Assuming a value of 0.013 for "*n*," a 3-in drain at a slope of ¼-in/ft has a full-flow capacity of approx 56 gpm, according to Manas and Eaton [13]. Utilizing the values of average discharge rates for the fixtures involved (see figs. 8, 10, and 11), assuming no attenuation of the discharge profile, and computing the effect on travel time caused by relative difference in velocity for a given rate of discharge as a function of flow depths, due to added discharge rate, the following values are obtained:

| Fixture(s) contributing load | Avg discharge rate | Ratio $h/d$ [a] | Theoretical reduction in travel time [b] | Measured reduction in travel time |
|---|---|---|---|---|
| | *gpm* | | % | % |
| L | 10.4 | 0.29 | — | — |
| L+M | 20.8 | .42 | 17 | 24 |
| K | 10.8 | .30 | — | — |
| J+K | 23.1 | .45 | 18 | 20 |
| U | 15.3 | .36 | — | — |
| U+V | 30.6 | .53 | 17 | 27 |

[a] Assuming "*n*" constant with flow depth, (*d*) is the diameter of the pipe and (*h*) is the depth of flow in the pipe.

[b] Due to increased discharge rate.

The discrepancy between the theoretical and measured values is explainable on the basis of attenuation of flow depth as the discharges move through the building drain. Such attenuation effects have been shown and discussed by Wyly [11] in a study of hydraulics of horizontal drains. The two principal factors are probably (1) the "peakiness" of the profile, e.g., the ratio of peak to average discharge rate from the fixture, and (2) the duration of the fixture discharge. For example, the discharge from a water closet with a short, peaky profile would be expected to attenuate at a high rate due to the relatively high gravitational forces tending to cause the "slug" to "slough off" at the ends, or to "flatten." By contrast, the discharge from a bathtub (or clothes washer) is characterized as relatively long-duration and non-peaky, and this would be expected to produce conditions approaching those to which the Manning formula applies. Therefore, in actuality the flow depths for water closet discharges would be expected to attenuate to magnitudes appreciably less than predicted from theory, and for bathtub discharges to be nearly in agreement with theory. Following this reasoning, the flow depth from a lavatory or sink would be expected to attenuate somewhat less than for the water closet, but more than for the bathtub. Examination of the curves representing the basic hydraulic elements of circular sewers [fig. 15–1, ref. 16] shows that the rate of reduction of velocity with reduction in flow depth is *increasingly greater* as flow depth is reduced.

Therefore, the greatest discrepancy between computed and actual reductions in travel time in the data shown here should be for the water closet, and the least for the kitchen sink. The data support this expectation; see preceeding tabulation.

Curves for four other fixtures are shown in figure 22. The bathtub curve (B) implies a very slight slowing down of the water with the distance traveled. This characteristic may be accounted for by the explanation offered above concerning attenuation of flow depth. The same explanation together with the long duration and essentially constant rate output of the dishwasher pump accounts for the nearly linear curve for the dishwasher.

Data were taken at only one station for the laundry tub and for the automatic clothes washer, but it is reasonable to suppose that had the additional data been taken the curves would have resembled the bathtub and the dishwasher curves, respectively.

For the fixture discharges (J*) and (J+K)* the food-waste-disposal unit was operating. From table 8, in a comparison with (J) and (J+K), respectively,

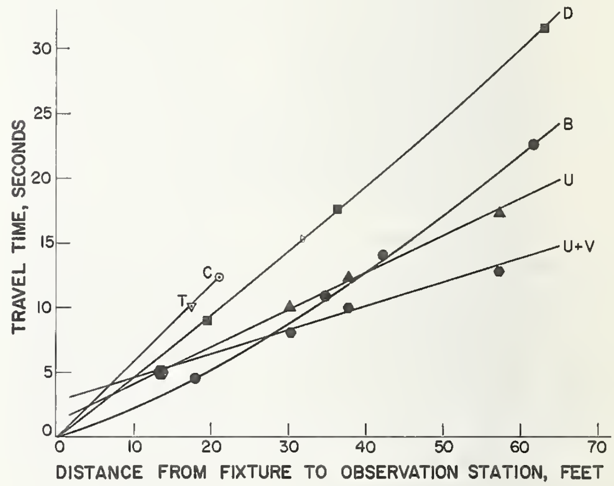


FIGURE 22. *Travel-times for water to reach measurement stations in building drain: comparison of various fixtures (split-level system)*

| Load Key | |
|---|---|
| Symbols | Fixture(s) discharged |
| B | Bathtub |
| C | Clothes washer |
| D | Dishwasher |
| T | Laundry tub |
| U | Top-story water closet |
| U+V | Top-story water closets back to back |

TABLE 9. *Detailed results: Comparisons of trap performance for several test loads*[a] *with main vent 1¼ in × 18 ft and all others ½ in × 25 ft* [b] *(split-level test system)*

| Fixture loadings with and without additives [c] | Trap-seal reductions, in inches, for fixtures identified by code | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | C | D | F | J | L | M | N | R | S | T | U | V | W |
| (L+M) | 0.02 | | | | 0.02 | | | | 0.02 | | | | | 0.54 |
| (L+M) with 8 ml detergent in each of L and M | .12 | 0.02 | 1.0 | | .20 | | | | | | | 0.66 | 0.12 | .18 |
| (J+K) | .13 | | | | .02 | | | | | | | .03 | .02 | |
| (C+N+T+W) | | | | | .06 | | | | | 0.33 | | | | |
| (U) | .30 | | .43 | | .35 | 0.06 | 0.04 | | | | | | .24 | |
| (B+U) | | | .56 | | .50 | .31 | .50 | | .16 | | | | .50 | |
| (B+U) with 16 ml detergent in (B) | | | | | | | | | | | | | .16 | 1.07 |
| (B+U) with 48 ml detergent in (B) | .07 | | .04 | | .05 | | | 0.04 | | | | | .07 | 2.50 |
| (B+L+U), 5, (C+W) | | | .60 | | .70 | | .50 | .36 | .94 | .29 | | | .50 | 0.16 |
| (B+L+U), 5, (C+W) with 200 ml detergent in (C) | | .48 | .60 | | .68 | | .50 | .52 | .25 | .38 | | | .50 | .12 |
| (U, 3, V) | .79 | | .96 | | .70 | .58 | .83 | .29 | .48 | .08 | | | | |
| (U, 5, V) | 1.28 | | .80 | | 1.00 | .78 | 1.00 | .42 | .80 | | | | | |
| (U, 7, V) | 0.88 | | .77 | | 1.00 | .64 | 0.70 | .48 | .52 | | | | | |

[a] See figure 18 for test system.
[b] Vent arrangement code 2 as described in table 7.
[c] See footnotes to tables 10 and 11 for explanation of load symbols.

without food-waste-disposal unit operating, the data indicate that the operation of the unit caused a definite slowing down of the water through the drainage system. Possibly the additional turbulence, vorticity or swirl could have accounted for this effect. Additional data for simultaneous and sequential discharges of fixtures are shown in table 8 together with their travel times and indicated rates of travel between measuring stations.

It should be realized that a portion of the travel time for the discharges of any of the fixtures on the second and third levels of the system was used up in the passage of the water down the soil stack at the velocity considerably in excess of the velocity that could be maintained in the building drain. This helps explain the relatively high velocities indicated for some fixtures in the first reach from the fixture to station No. 1 (see data for B,L,L+M). This explanation, however, does not account for the data for the water closets, probably because of the delay due to initiation of flushing action (and to collision of the streams in the stack for load U+V).

The data in table 8 provided guidance in the selection of load sequences intended to concentrate the discharges within particular reaches of the drainage system, and offered further support for the general hypothesis that accurate measurements of velocities, depths, and discharge profiles in a horizontal drain serving multiple fixtures may provide a convenient and economical way to obtain needed load data, providing that the system can be precalibrated to correlate the measured parameters with known fixture loadings and that computer processing of the data is systematically planned for.

### 3.5.3. Transportability of Solids

In tests made with pieces of sponge flushed through one of the top-story water closets (see sec. 3.4 for description), it was found that with a flush of one piece, the specimen passed completely through the system in successive trials. When flushing two or three pieces, one or more of the specimens usually stayed in

TABLE 10. *Summary of results: Comparison of trap performance for different venting arrangements with various clean-water loads*[a] *(split-level test system*[b]*)*

| Listing Number | Vent arrangement code[c] | Main vent: Diam (Inches) | Main vent: Length (Feet) | Main vent: Condition | All other vents: Diam (Inches) | All other vents: Length (Feet) | All other vents: Condition | Test load[i] fixture combinations/sequences[ghi] | Number of fixtures discharged | Number of trap seals reduced by more than 1 Inch |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1¼ | 18 | Open | 1½[d] | 5 | Open | (U+V), 5, W | 3 | None[k] |
| 2 | 2 | 1¼ | 18 | Open | ½ | 25 | Open | U; (J+K); L+U; B+U; B+L+U; C+N+T+W; (U+V), 3, W; (B+L+U), 5, W; (B+L+U), 5, (C+W) | 1; 1; 2; 2; 3; 4; 3; 4; 5 | None |
| 3 | 2 | 1¼ | 18 | Open | ½ | 25 | Open | U+V; (U+V), 5, W | 2; 3 | 3 |
| 4 | 2 | 1¼ | 18 | Open | ½ | 25 | Open | (U+V), 7, W; (B+L+U+V), 5, (C+W) | 3; 6 | 2 |
| 5 | 3 | 1 | 1 | Open | ½ | 1 | Open | U; L+U | 1; 2 | None |
| 6 | 4 | 1 | 1 | Open | ½ | 25 | Open | U; (J+K); L+U; C+N+T+W | 1; 1; 2; 4 | None |
| 7 | 5a | ½ | 1 | Open | ½ | 1 | Open | U; (J+K); L+U; C+N+T+W | 1; 1; 2; 4 | None |
| 8 | 5b | ½ | 1 | Open[e] | ½ | 1 | Open[f] | U | 1 | 1 |
| 9 | 6 | ½ | 25 | Open | ½ | 25 | Open | C+N+T+W | 4 | None |
| 10 | 6 | ½ | 25 | Open | ½ | 25 | Open | U | 1 | 3 |
| 11 | 6 | ½ | 25 | Open | ½ | 25 | Open | U+V | 2 | 4 |
| 12 | 6 | ½ | 25 | Open | ½ | 25 | Open | L+U | 2 | 5 |
| 13 | 7 | ½ | 50 | Open | ½ | 50 | Open | U | 1 | 5 |
| 14 | 7 | ½ | 50 | Open | ½ | 50 | Open | U+V | 2 | 2 |
| 15 | 7 | ½ | 50 | Open | ½ | 50 | Open | B+L+M+U+V | 5 | 6 |
| 16 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | W; L; M; N; B; J; J*[j]; K; K*; D; C; T; D+T | 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 2 | None |
| 17 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | U; C+N+T+W | 1; 4 | 4 |
| 18 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | V; B+C+D+J+K+L+M+N+T+U+V+W; (D+J+K), 2, (B+L+M+U+V) | 1; 11; 7 | 2 |
| 19 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | (J+K); (J+K)* | 1; 1 | 1 |
| 20 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | U+V; L+U; B+V; L+M | 2; 2; 2; 2 | 5 |
| 21 | 8 | ½ | 50 | Closed[f] | ½ | 50 | Closed[f] | B+L+M+U+V | 5 | 3 |

[a] Water at ambient cold temperature.

[b] See figure 18 showing test system. Building drain 3-in diam upstream of laundry group, 4-in downstream.

[c] See table 7 for explanation of Code.

[d] Vent to (W) was nominal 3-in diam × approx. 4-ft long, reduced to 2½-in diam at terminal by orifice.

[e] Vents to kitchen sink and dishwashing machine closed.

[f] Closed by sealing terminals. Internal volume of each vent was approx. ½ gal.

[g] B = bathtub, C = automatic clothes washer, D = dishwasher, J = compartment of the kitchen sink not over trap and K = compartment of sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture. L and M are back-to-back lavatories on the top level, N is a lavatory on the bottom level, T = concrete laundry tub, U and V are back-to-back water closets on the top level and W is a water closet on the bottom level.

[h] Three types of symbols are used to designate the fixtures discharged to compromise a test load: (a) simultaneous discharge of group such as All = B+C+D+(J+K)+L+M+N+T+U+V+W, (b) partial simultaneous; All − (J+K) = all fixtures except the two-compartment kitchen sink, (c) sequential; W, 2, (B+J) = water closet W followed by a 2-second pause followed by simultaneous discharge of the bathtub and compartment J of the kitchen sink.

[i] A single trap served the two-compartment sink (J+K).

[j] For the J*, K* and (J+K)* loads the food-waste disposal unit was operated during the discharge of the sink compartment(s).

[k] Similar results with nominal 3″ diam. building drain upstream of lowest-level bathroom group and nominal 4″ diam downstream of bathroom group, see figure 18.

TABLE 11. *Summary of results: Comparison of trap performance for clean water loads and similar loads containing detergent or solids additives*[a], *with three venting arrangements (split-level test system*[b])

| Vent arrangement code[c] | Main vent | | | All other vents | | | Test load: fixture combination/sequences[d e] | Additives | Number of fixtures discharged | Number of trap-seals reduced by more than 1 inch |
|---|---|---|---|---|---|---|---|---|---|---|
| | Diam | Length | Condition | Diam | Length | Condition | | | | |
| | Inches | Feet | | Inches | Feet | | | | | |
| 1 | 1¼ | 18 | Open | 1½ | 5 | Open | U+V, 5, W | Clean water[f g h i] | 3 | None |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | U+V, 5, W | Clean water[i] | 3 | 3 |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | U+V, 7, W | Clean water[i] | 3 | 1 |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | L+M | Clean water[i] | 2 | None |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | L+M | Clean water[j] | 2 | None |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | L+M | 8 ml of liquid detergent in each lavatory[j] | 2 | 1 |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | B+U | Clean water[i] | 2 | None |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | B+U | 16 ml/of liquid detergent in each bathtub[k] | 2 | 1 |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | B+L+U, 5, C+W | 200 ml of detergent powder in clothes washer | 5 | None |
| 2 | 1¼ | 18 | Open | ½ | 25 | Open | B+L+U, 5, C+W | Clean water[i] | 5 | None |
| 5a | ½ | 1 | Open | ½ | 1 | Open | J+K | Clean water[i] | 1[l] | None |
| 5a | ½ | 1 | Open | ½ | 1 | Open | J+K | 16 ml of liquid detergent in each compartment of sink | 1[l] | None |
| 5a | ½ | 1 | Open | ½ | 1 | Open | (J+K)*[m] | 16 ml of liquid detergent in each compartment of sink. System not purged of suds between successive test runs | 1 | None |
| 5a | ½ | 1 | Open | ½ | 1 | Open | U | 3 solids in water closet U | 1 | None |

[a] Some loads involved hot water, others cold.
[b] See figure 18 showing test system.
[c] See table 7 for explanation of code.
[d] B = bathtub, C = automatic clothes washer, J = compartment of kitchen sink not over trap and K = compartment of the sink over trap, (J+K) indicates that the two compartments were discharged simultaneously acting as a single fixture. L and M are back-to-back lavatories on top level, U and V are back-to-back water closets on top level and W is a water closet on bottom level.
[e] Groups of symbols are used to designate the fixtures discharged to comprise a test load: (a) simultaneous discharge of group such as B+U, (b) sequential; B+L+U, 5, C+W, simultaneous discharge of bathtub, lavatory L and water closet U followed 5 seconds later by simultaneous discharge of the automatic clothes washer and water closet W.
[f] See figure 18, nominal 3-in diam building drain upstream of laundry group. Nominal 4-in diam building drain downstream of laundry group.
[g] Similar results with nominal 3″ diam building drain upstream of basement bathroom group, and nominal 4″ diam downstream of basement bathroom group; see figure 18.
[h] Vent to (W) was nominal 3-in diam × approx 4-ft long, reduced to 2½-in diam at terminal by orifice.
[i] Cold water as drawn from supply piping (approx 25 deg C).
[j] Hot water in range of 46 deg C to 56 deg C.
[k] Hot water in range of 58 deg C to 64 deg C
[l] A single trap served the two-compartment sink (J+K)
[m] For the J*, K* and (J+K)* loads the food-waste disposal unit was operated during the discharge of the sink compartment(s).

the system (probably within the building drain) until washed through with a second or third flush with clean water. The water closet did not flush effectively with four or more pieces of sponge, hence no more than three pieces were used in the subsequent trap performance test made with the sponge pieces in the load.

#### 3.5.4. Trap Performance With Various Loads and Venting Arrangements

Tables 9, 10, and 11 summarize the measurements of trap performance with various loads and venting arrangements, obtained by the procedure described in section 3.4. Some of the results are illustrated by graphs in figures 23 through 34.

Table 9 compares trap-seal reductions for several test loads with venting arrangement 2 as described in table 7 (main vent 1¼-in x 18-ft, all others ½-in x 25-ft). These data provide the basis for the following observations:

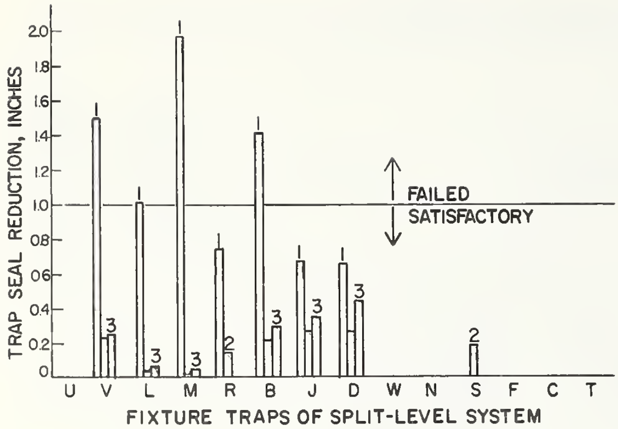


FIGURE 23. *Effect of vent resistance on trap performance for cold, clean-water load U (split-level system, averages for measurements in triplicate)*

| Symbol | Main vent | | All vents other than main | | vent code |
|---|---|---|---|---|---|
| | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | ½ | 25 | ½ | 25 | 6 |
| 2 | 1 | 1 | ½ | 25 | 4 |
| 3 | 1¼ | 18 | ½ | 25 | 2 |

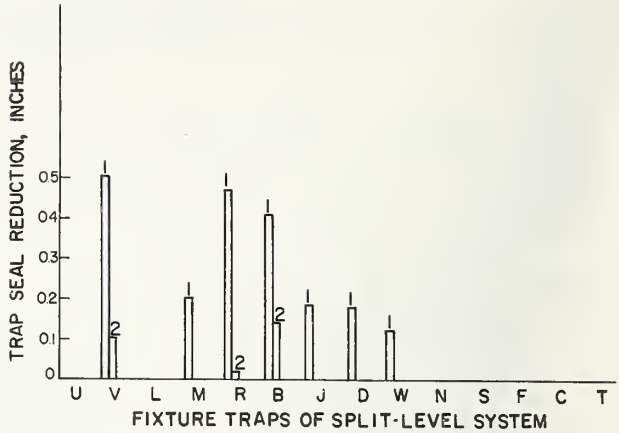


FIGURE 24. *Effect of vent size on trap performance for cold, clean-water load L+U (split-level system, averages for measurements in triplicate)*

| Symbol | Main vent | | All vents other than main | | Vent code |
|---|---|---|---|---|---|
| | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | ½ | 1 | ½ | 1 | 5a |
| 2 | 1 | 1 | ½ | 1 | 3 |

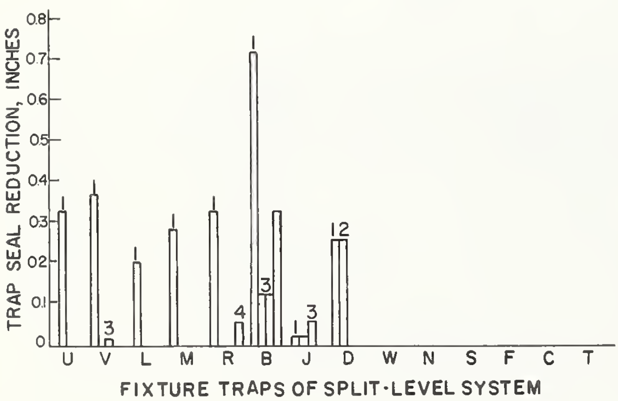


FIGURE 25. *Effect of vent resistance on trap performance for cold, clean-water load J+K (split-level system, averages for measurements in triplicate)*

| Symbol | Main vent | | All vents other than main | | Vent code |
|---|---|---|---|---|---|
| | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | ½ | 25 | ½ | 25 | 6 |
| 2 | 1 | 1 | ½ | 25 | 4 |
| 3 | 1¼ | 18 | ½ | 25 | 2 |
| 4 | ½ | 1 | ½ | 1 | 5a |

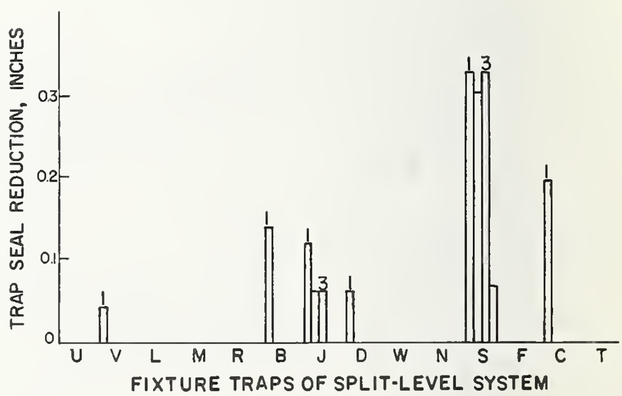


FIGURE 26. *Effect of vent resistance on trap performance for cold, clean-water load C+N+T+W (split-level system, averages for measurements in triplicate)*

| Symbol | Main vent | | All vents other than main | | Vent code |
|---|---|---|---|---|---|
| | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | ½ | 25 | ½ | 25 | 6 |
| 2 | 1 | 1 | ½ | 25 | 4 |
| 3 | 1¼ | 18 | ½ | 25 | 2 |
| 4 | ½ | 1 | ½ | 1 | 5a |

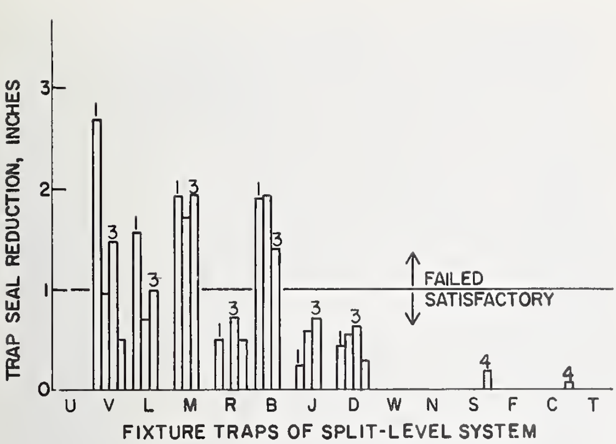


FIGURE 27. *Effect of vent resistance (including all vents closed) on trap performance for cold, clean-water load U (split-level system, averages for measurements in triplicate)*

| Symbol | Condition of all vents | Main vent | | All vents other than main | | Vent code |
|---|---|---|---|---|---|---|
| | | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | Closed | ½ | 50 | ½ | 50 | 8 |
| 2 | Open | ½ | 50 | ½ | 50 | 7 |
| 3 | Open | ½ | 25 | ½ | 25 | 6 |
| 4 | Open | ½ | 1 | ½ | 1 | 5a |

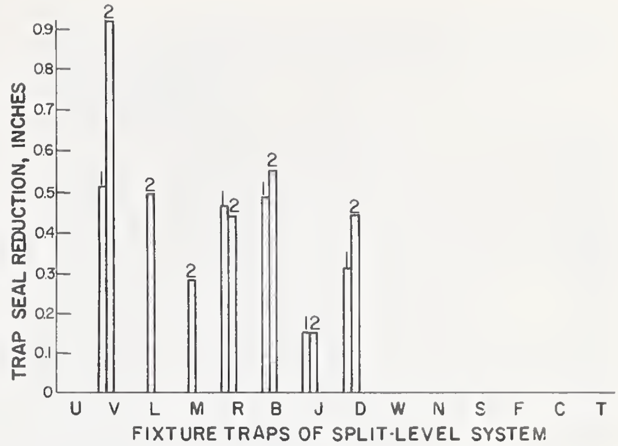


FIGURE 28. *Effect of closing sink and dishwasher vents on trap performance for cold, clean-water load U (split-level system, averages for measurements in triplicate)*

| Symbol | Condition of sink and dish washer vents | Main vent | | All vents other than main | | Vent code |
|---|---|---|---|---|---|---|
| | | Diam In | Length Ft | Diam In | Length Ft | |
| 1 | Open | ½ | 1 | ½ | 1 | 5a |
| 2 | Closed | ½ | 1 | ½ | 1 | 5b |

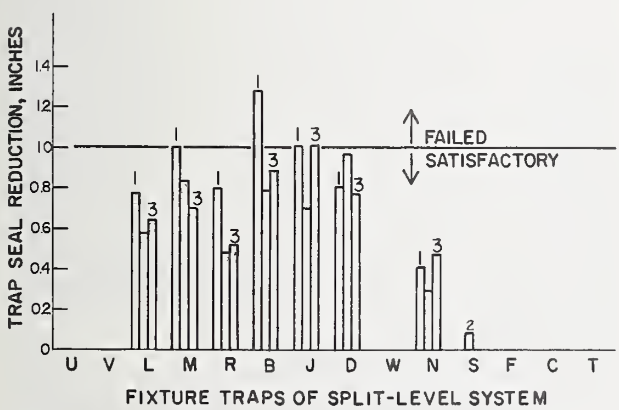


FIGURE 29. *Effect of time sequence on trap performance for cold, clean-water multi-fixture load U+V, t, W with vents in accordance with vent code 2 (split-level system, averages for measurements in triplicate)*

| Symbol | Time delay, *t* s |
|---|---|
| 1 | 3 |
| 2 | 5 |
| 3 | 7 |

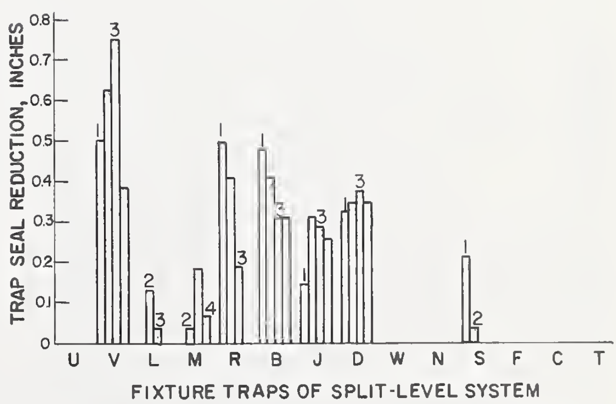


FIGURE 30. *Effect of solids on trap performance for cold water load U, with vents in accordance with vent code 5a (split-level system, averages for measurements in triplicate)*

| Symbol | Number of sponge pieces flushed |
|---|---|
| 1 | None |
| 2 | 1 |
| 3 | 2 |
| 4 | 3 |

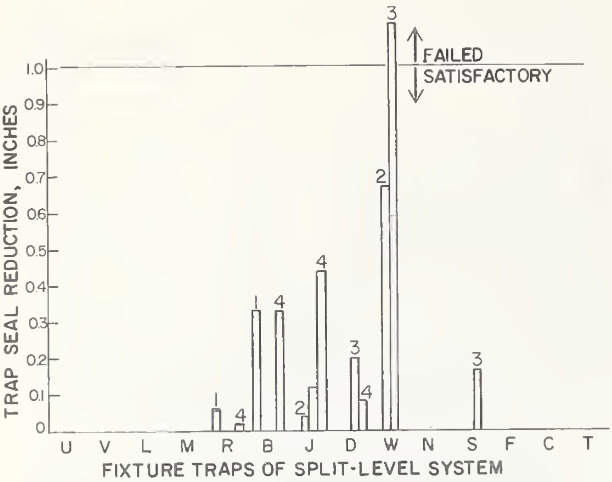


FIGURE 31. *Effect of 16 ml liquid detergent in each sink compartment on trap performance for cold-water loads $J+K$ and $(J+K)$*, with vents in accordance with vent code 5a (split-level system, averages for measurements in triplicate)*

| Symbol | Detergent | Fwdu operating | System purged between runs |
|---|---|---|---|
| 1 | No | No | —— |
| 2 | Yes | No | No |
| 3 | Yes | Yes | No |
| 4 | Yes | Yes | Yes |

* Food-waste disposal unit operating.

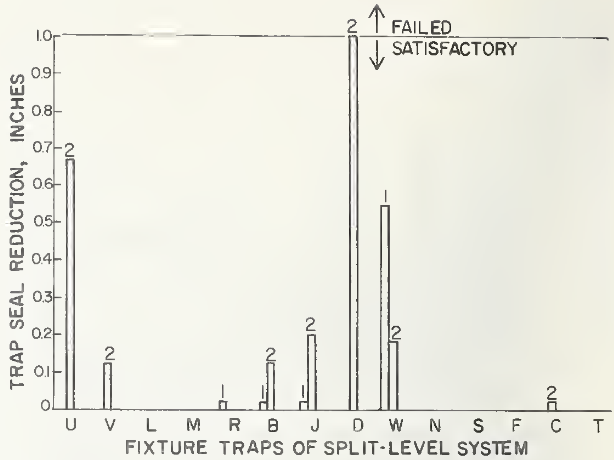


FIGURE 32. *Effect of 8 ml liquid detergent in back-to-back lavatories on trap performance for cold-water load $L+M$, with vents in accordance with vent code 2 (split-level system, averages for measurements in triplicate)*

| Symbol | Condition |
|---|---|
| 1 | Clean water in L and M |
| 2 | 8 ml liquid detergent in each of L and M |

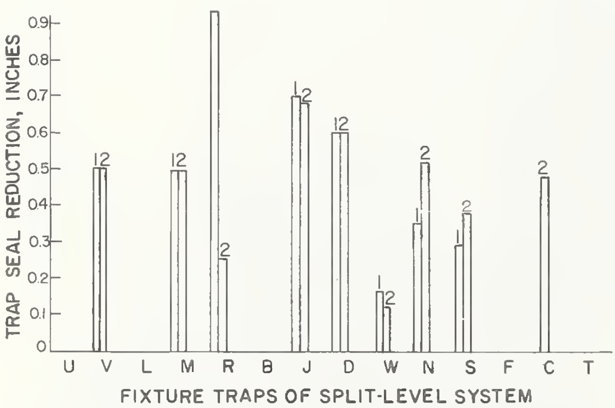


FIGURE 33. *Effect or 200 ml granulated detergent in clothes-washing machine on trap performance for cold-water load $B+L+U$, 5, $C+W$, with vents in accordance with vent code 2 (split-level system, averages for measurements in triplicate)*

| Symbol | Condition |
|---|---|
| 1 | Clean water in each fixture |
| 2 | 200 ml granulated detergent in C |

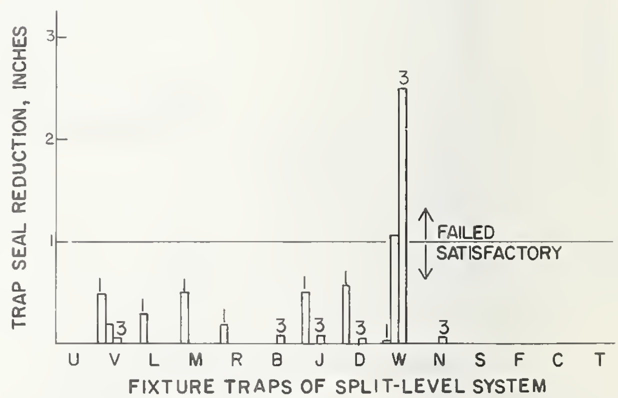


FIGURE 34. *Effect of two different concentrations of liquid detergent in bathtub on trap performance for cold-water load $B+U$, with vents in accordance with vent code 2 (split-level system, averages for measurements in triplicate)*

| Symbol | Quantity of detergent in B |
|---|---|
| 1 | None |
| 2 | 16 ml |
| 3 | 48 ml |

1. The discharge of the two top-story lavatories together with detergent produced a near-failure of the trap seal in the dishwasher (1.0-in reduction).

Subsequent investigation using other load patterns with detergents showed that where several successive test runs were made without alternating with clean-water flushes, as was the case for figure 30, there was a tendency to excessive detergent buildup, to the extent that the system could be shown to fail with standard-size vents. Evidently the particular test shown in figure 30 was not repeated using alternating clean-water flushes.

2. When one of the water closets and the bathtub in the top-story group were discharged together with detergent in the bathtub, failure of the basement water-closet-trap seal occurred (1.07 in) and the failure was worsened when the detergent concentration was tripled (2.50 in), as shown in figure 34.

3. Based on the data from a five-fixture time-sequence load that included the clothes washer, comparison of results with and without detergent in the clothes-washer did not show a significant effect attributable to the detergent. This is illustrated in figure 33. The reasoning in selecting the particular time sequence in this load was that calculations derived from the travel time data illustrated in figures 21 and 22 indicated that such a delay would tend to concentrate the discharge of all the fixtures in the building drain during the same period of time. It was presumed this would produce the worst condition with detergents in the load.

4. Table 9 shows the results of experimentation with the simultaneous discharge of the two top-story water closets, with a time delay between the discharge of the first and second fixtures. These data show that all the idle traps on the top floor were affected most by a 5-s delay, next most by a 7-s delay, and least of all by a 3-s delay. Any relationship between trap-seal reduction and time delay that might have existed for the intermediate and lower floor traps was obscure. A failure occurred in one of the seven idle traps for which data were obtained and borderline performance occurred in two additional ones, with the 5-s delay. Borderline performance in one trap occurred with the 7-s delay (no failures), and the least trap-seal reductions occurred with a 3-s delay (max trap-seal reduction 0.96 in).

Table 10 compares trap-seal reductions for different venting arrangements with various loads. One or more vents were of smaller size than customary, in each test, and in some of the tests some or all of the vents were closed.

When all vents were closed, the loads comprising two or more fixtures caused failure of one or more traps. Although no tests were made on the split-level system with a common manifold terminal for the various vents, consideration of the results of the tests on the slab-on-grade system in the context of the recirculation hypothesis indicates that trap-seal failures may not have occurred with at least some multi-fixture loads had a manifold terminal been closed rather than the individual vents.

With ½-in x 50-ft or 1/2-in x 25-ft tubing for all vents, the loads involving one or both of the top-story water closets produced failure of one or more trap seals.

With ½-in x 25-ft tubing for all vents except the main vent, which was 1¼-in x 18-ft, only loads that included the discharge of both top-floor water closets produced trap-seal failures. With all vents 1½-in x 5-ft except the main vent, which was 1¼-in x 18-ft, a three-fixture load involving both top-story water closets did not produce any trap-seal failures.

Table 11 compares trap-seal reductions for clean-water loads and similar loads containing detergent or solids additives, with three venting arrangements.

One or more vents were of smaller size than customary in each test. All vents were open in all the tests for the results given in table 11.

With vent arrangement 1 (main vent 1¼-in x 18-ft and all others 1½-in x 5-ft), a three-fixture clean-water load made up of all three water closets was applied, first with the 4-in building drain beginning at the connection of the laundry group, and then with it beginning at the connection of the basement bathroom. No significant difference was observed in trap performance.

The following observations are offered, based on examination of the data in table 11:

1. With vent arrangement 2 (main vent 1¼-in x 18-ft and all others ½-in x 25-ft), clean-water loads that included the simultaneous discharge of both top-story water closets produced failure of one or more trap seals.

2. With vent arrangement 2, simultaneous discharge of the two back-to-back top-story lavatories containing hot water and liquid detergent caused the failure of one trap seal. By comparison, the same load without the detergent caused no trap-seal failure. A similar result occurred with the simultaneous discharge of one of the water closets and one of the bathtubs on the top story, using clean cold water in the bathtub in comparison with hot water and detergent.

3. With vent arrangement 2, a five-fixture load was applied that included the discharge of three of the six fixtures in the two top-floor back-to-back bathrooms as well as the clothes washer and the basement water closet, first with clean water in the clothes washer and then with a representative amount of powdered detergent in the clothes washer. The use of detergent powder in the clothes washer did not produce a trap-seal failure.

4. With vent arrangement 5a (all vents ½-in x 1-ft) the two sink compartments were discharged first with clean water, then with liquid detergent, and finally with liquid detergent while operating the food-waste-disposal unit without alternating flushing with clean water between test runs. No trap-seal failures were produced with either of the three types of load.

Figures 23 through 28 compare trap-seal reductions for different degrees of vent resistance (e.g., size, length, closure). These figures show that in general:

1. The closure of all vents caused the failure of several trap seals for a load consisting of one top-story water closet.

2. The use of ½-in tubing 50 ft or 25 ft long for all vents produced failure of some trap seals for a load consisting of one top-story water closet.

3. The use of ½-in tubing 1 ft long for all vents did not produce failure of any trap seals for the following loads:

(a) Discharge of one top-floor water closet.

(b) Simultaneous discharge of one top-floor water closet and one top-floor lavatory.

(c) The discharge of both compartments of the sink together.

(d) The simultaneous discharge of all lower-level fixtures (four, omitting floor drain and shower).

4. The use of either a 1-in x 1-ft or 1¼-in x 18-ft main vent, and ½-in x 25-ft tubing for all others produced satisfactory trap-seal performance for all the loads indicated in items 3(a)–3(d) above.

Figure 28 shows that the discharge of one top-story water closet produced substantially greater trap-seal reductions with the sink and dishwasher vents closed, but did not cause failure.

Figure 29 shows that more of the trap seals were adversely affected more by a time delay of 5s than by either 3s or 7s in a 3-water-closet load. This may have been due in part to a critical concentration of water in the building drain. The trap performance was marginal, with some failures of top-story and kitchen-level fixtures. This finding is similar to that for the 2-water-closet load discussed near the beginning of this section.

Figure 30 compares trap-seal reductions caused by the discharge of one top-story water closet with and without solids (see section 3.4 for method). For these tests, all vents above the fixture flood levels were reduced to ½-in x 1-ft. In some cases the clean-water load produced the greatest trap-seal reductions, while in other cases the greater reductions occurred when flushing one or more of the pieces of sponge, representing feces. Trap-seal reductions did not exceed ¾ in on the top floor and ⅜ in on the intermediate floor. Reductions were negligible on the bottom floor.

Figure 31 compares trap-seal reductions caused by the discharge of the kitchen sink with and without detergent. The data also compare reductions with and without the food-waste-disposal unit operating, and with and without purging the system with clean water between the successive detergent runs. For these tests all the vents above the fixture flood levels were reduced to ½-in x 1-ft.

These data show that the greatest seal reductions in the idle trap seals on the lowest and intermediate floors occurred when detergent was used, and that the greatest reductions in those traps occurred when the food-waste-disposal unit was operated and the successive test runs were made without clean-water flushing between runs. By contrast, such trap-seal reduction as occurred in the idle top-story traps were greatest either with clean water or with detergent in conjunction with clean-water flushing between tests.

Figure 32 compares trap-seal reductions caused by the simultaneous discharge of both top-story lavatories, with and without detergent. For these tests, all vents above fixture flood levels were reduced to ½-in x 25-ft except the main vent, which was 1¼-in x 18-ft.

For most of the idle traps the greatest trap-seal reductions were associated with the detergent loadings. Although the converse is shown for the bottom-story water closet (W), this may have been affected by an excess of suds accumulated in the building drain from previous testing with detergents before starting the clean-water test runs.

The greatest reduction occurred in the dishwasher trap on the intermediate floor, but did not exceed 1-in with the detergent loading.

Figures 33 and 34 compare trap-seal reductions with and without detergents for two different loads. For these tests, all vents were reduced as described above for figure 32. In these tests, the greatest trap-seal reductions on the top and intermediate stories occurred with the clean-water loads in most instances. As for the other detergent tests shown in figures 31 and 32, one or more of the trap seals on the bottom story were adversely affected by the addition of the detergents in each test shown in figures 33 and 34. Only in figures 31 and 34 did the reductions exceed 1 in, and in both instances this occurred in the bottom-story water closet (W).

In reviewing the results of the detergent tests shown in this paper it is important to recognize the complexity of the phenomena associated with detergent loading, and to remember that for most of the data shown the tests were made without any systematic clean-water purging between detergent runs.

### 3.6. Summary

The tests made utilizing several variations of size and length of vents of the three-bath, split-level DWV system provided further support for the hypothesis that with competent engineering design and evaluation, two- and two-and-one-half story systems need not be provided with dry vents as large as presently specified by codes. However, the data obtained clearly show that for equivalent trap-seal protection, the split-level system required vents capable of delivering significantly greater rates of air flow than were required for the slab-on-grade system.

Trap performance with all vents of ½-in diam x 25-ft length was inadequate with a number of realistic loads, although it was marginal when the main vent was increased to a size giving approximately the resistance offered by a 1¼-in steel pipe 18-ft long. The nature of the trap performance with this arrangement indicated that with a 1¼- or 1½-in main vent and ¾- or 1-in sizes for the other vents, performance might well have been satisfactory with all realistic loads. Unfortunately, it was necessary to terminate the study before such tests could be made.

The tests with detergents showed that some load patterns with detergents produced greater trap-seal reductions than similar clean-water loads, particularly

in the lowest branch interval. Test loads with detergents repeated several times in succession without alternating flushes with clean water produced results that suggested a build-up of suds concentration in the system as a leading cause of the trap-seal failures observed both with reduced-size and customary-size vents. Thus, in testing with detergents, heavy concentrations and successive loading without alternating clean-water purges probably should be avoided, if realistic test results are to be obtained. In the absence of appropriate field data, detergent load patterns suitable for test purposes cannot be scientifically defined (e.g., concentration, clean-water purging, temperature, etc.). For the time being the choices should be determined through a consensus of current experts in this field.

Tests with detergents in which the effect of water temperature was investigated showed that greater effects occurred with hot water than with cold, other factors being equal.

## 4. Development of a Table for Sizing Vents Based on Functional Requirements

For practical use by the designers of plumbing systems and by approval authorities, it is important that sizing rules be presented in a simple format and in terms familiar to the plumbing trade, e.g., magnitude and distribution of fixture load, configuration, and dimensions.

A review of the state of the art underlying the vent-sizing rules presently contained in most plumbing codes shows that large safety factors were used in applying the results of experimental studies. This conservatism has long been considered necessary principally because of the following reasons:

1. The experimentation on which the sizing rules of codes are based was incomplete in scope, and was necessarily conducted with instrumentation and data analysis techniques considered primitive by today's standards.
2. Wide variations in configuration and dimensional detail occur at the installation state in traditional site-built systems, even for systems designed as identical, and some of these variations may cause substantial effects on air demand.
3. Wide variations in hydraulic load patterns probably occur for a variety of reasons, and such variations can substantially affect the functioning of venting systems. In the code sizing rules, worst-case conditions are assumed.
4. Environmental conditions such as temperature, wind, local sewer flow, and gas-generating characteristics, etc., may affect the functioning of venting systems. The scope of the early experimentation did not fully cover all these points.

The work described herein is an extension of the work on venting begun at NBS after World War II. Some instrumentation capable of producing a recording of simultaneous dynamic phenomena at several stations in the test setup was utilized. Also, the work emphasized examination of the performance of potential solutions currently unacceptable under the contemporary model codes. In much of the previous work, the emphasis had been on supplying a scientific rationale for the design specifications on pipe sizing typically presented in codes, and on the development of performance data for traditional solutions acceptable to codes through the test of experience.

The generally accepted theory underlying the sizing of main vents [15] begins with these primary assumptions, in effect:

1. There is no "slippage" between the air and water as the water falls down a drainage stack, i.e., the water falls at terminal velocity in an annulus in contact with the wall of the stack and drags the air in the inner "core" with it at a mean velocity equal to the computed mean terminal velocity of the water.
2. All the air dragged *down* the drainage stack of a multi-story system by the falling water must be relieved *upward* through the vent stack.
3. No pressure or vacuum relief occurs due to recirculation of air between the elements of a DWV network (e.g., between active and idle elements).
4. It is necessary to size all vents to accommodate computed peak air demand with a pressure drop limited to 1 in of water column.
5. No vent may be of a diameter less than 1¼-in (some codes specify a 1½-in minimum) or one-half the diameter of the drain which it vents, whichever is greater.
6. Any structure in which a building drain is installed must have at least one stack vent or vent stack extending to the atmosphere with a diameter of not less than 3-in, or of not less than the size of the building drain if such building drain is less than 3-in in diameter.
7. Where frost closure is likely, all vent terminals must be at least 3 in in diameter. Where local experience supports the need for a larger diameter, the change in diameter to an appropriate fitting must be made at least 1 ft below the roof.

A realistic review of existing information shows that a number of the foregoing assumpions are either unfounded, irrelevant, or only partially true in the context of modern plumbing design, particularly where industrialized building methods are utilized.

The concept of reduced-size venting was recognized to some degree in 1940 by the Central Housing Committee on Research Design and Construction [5]. In this concept, stack vents could be reduced to sizes less than those of the corresponding soil or waste stacks, if the connected fixture-unit load was less than one-half the allowable load with full-size vents and the system had horizontal branches in not more than two branch intervals. The sizing table offered for this situation was the same as for sizing vent stacks or main vents

(see para. 1014 and table 1013, ref. 5). Taking a conservative interpretation of this rule, one could have obtained a stack vent (main vent) size of 1½-in for either of the two complete experimental DWV systems described herein. By extrapolation of table 1013, still smaller sizes could have been inferred.

Data on air demand in components [1, 2, 3] was reviewed to obtain some idea of the relationship between air demand, vent pressure, fall distance, and rate of water input. Computations and inferences of minimum vent sizes from this approach were compared with the trap performance data obtained from the two complete DWV test systems that were constructed with selected reduced-sizes. Also, the measured air-flow rates in vents obtained in the tests with components and with the complete one-story test system were compared with the values computed from generally accepted theory, and the minimum vent sizes indicated by the two different approaches were compared. This procedure showed the code-specified sizes to be the largest, the sizes obtained from direct computation from Monogr. 31 theory [15] the next smaller, and the sizes computed from measurements of actual air demand or shown adequate by trap performance of the complete DWV systems the smallest. The data also showed it reasonable that for equal performance, the vents for the split-level system had to be of greater diameters than for the one-story, slab-on-grade system.

Following the approach indicated, table 12 was produced. It takes into account the important parameters affecting air demand through system configuration and vertical distribution of plumbing fixtures, the effect on air demand due to position of the vent element in the system, and the effect of magnitude of connected fixture load served by the vent. Connected fixture load is frequently characterized in terms of fixture units, a term which had been carefully explained by Eaton and French [17].

TABLE 12. *Guide for sizing reduced-size vents for one- and two-story systems*

| Type of system | Type of vent [a] | Fixture-unit load served by vent [b] | Size of vent [a] (in) |
|---|---|---|---|
| One-story, slab-on grade or crawl space (fixtures within one branch interval only) | Individual vent [d] | Up to 3 f u | ½ |
| | | 4–6 f u | ¾ |
| | Common vent [d] or branch vent [d] | Up to 3 f u | ¾ |
| | | 4–6 f u | 1 |
| | Main stack (soil or waste) vent [c] | Up to 6 f u | 1 |
| | | 7–15 f u | 1¼ |
| Two-story (fixtures in not more than 2 branch intervals), or split-level system (fixtures distributed between not more than 3 levels over a vertical span of not more than 15 ft) | Individual vent [d] | Up to 3 f u | ½ |
| | | 4–6 f u | ¾ |
| | Common vent [d] or branch vent [d] | Up to 3 f u | ¾ |
| | | 4–6 f u | 1 |
| | | 7–12 f u | 1¼ |
| | | 13–20 f u | 1½ |
| | Main stack (soil or waste) vent ([c]) or vent stack | Up to 6 f u | 1¼ |
| | | 7–15 f u | 1½ |
| | | 16–30 f u | 2 |

[a] Dry vents only. Sizes estimated on the basis of research data on two full-scale laboratory systems.

[b] Some adjustments in range limits may prove necessary for some systems, depending on configuration. Engineering judgment should be exercised in such instances.

[c] Assumed size of soil stack 3 in. It is assumed the soil vent may provide direct ventilation for two or more fixture traps on the top floor.

[d] For the purpose of this table, it is assumed that these vents are less than 25 ft in length, and that the water does not have an unbroken fall of more than 5 ft in the waste stack or vertical waste pipe to which the trap-arm connects and which is being vented by the indicated vent.

## 5. Conclusions and Recommendations

The study showed that, within the scope of the investigation, many DWV systems in one-story and split-level houses can be designed to provide essential trap performance with vents much smaller than usually required by codes.

The data presented herein, taken together with the data on the air demand-vent pressure relationship obtained on component systems, have provided the basis for table 12 which can be looked upon as a guide. It does not take the place of engineering judgment and experience by the plumbing designer, particularly when systems differ substantially in configuration from those so far studied.

In the utilization of reduced-size venting for split level and one- and two-branch interval slab-on-grade or traditional houses, it is important that several simple rules be observed by designers and installers, that are not necessarily relevant to traditional DWV systems:

1. Reduced-sizes should not be installed below a point approximately 6 in above the flood rim of the fixtures served. Vents for single-bowl sinks with food-waste disposal units should not be reduced below the elevation corresponding to the shut-off head of the unit. These measures are necessary to minimize the fouling or clogging effects of intermittent deposits of particulate matter in reduced-size vents over a period of time in normal service.

2. Reduced sizes should be used for dry vents only. Thus, wet vents or reaches of vents designed as dry vents, but nevertheless likely to be intermittently submerged or subjected to wetting by aerosols or suds, should be designed to conventional sizes.

3. The cross-sectional area of a manifold vent or vent header (a vent terminal to which two or more smaller vents are connected) should be greater than the largest of the vents connected to it, but if three or

more vents connect to the manifold, the manifold area need not equal the sum of the connected areas. Probably, a size of one commercial pipe size larger than the largest connected vent should suffice for the DWV system usually installed in housing construction.

4. In areas where frost closure may occur, vent terminals should be sized to account for the effects of local weather as explained by Eaton and Wyly [18]. The use of vent piping that has low thermal conductivity, or the use of some other means for reducing or counteracting natural heat loss might be employed to reduce the likelihood of frost closure. Reduced-size vents should not run through unheated spaces where frost closure is likely.

5. Vent terminals serving reduced-size vents should be fitted with durable, corrosion-resistant enlarged caps of screen having open areas greater than the cross-sectional area of the vent terminal, so as to provide an allowance for clogging of the screen and to prevent entrance of leaves and insects into the vent system. Probably an open area 50 percent greater than the area of the terminal is adequate.

6. All vent piping should be positioned, supported, and continuously graded so that condensation or other moisture will drain by gravity to (a) a soil or waste pipe, or (b) to an acceptable location outside the structure, provided that this solution is not employed in frost-closure-prone areas without suitable protection against freezing

7. Reduced-size vents should be made of material that does not contribute to substantial reduction in diameter from scale formation or other causes under ordinary conditions of use.

This study examined the performance of reduced-size venting as employed in full-scale laboratory systems simulating sanitary DWV systems of one-story and split-level houses. Various combinations of the plumbing fixtures were discharged to produce a range of hydraulic loadings, and many different venting arrangements were utilized, for each system. Most of the testing was done with clean-water loads, but some tests involved detergents or solids.

The results suggest that reduced-size venting could be successfully used for the venting of sanitary drainage systems of greater heights, and to systems with more complex vent-system configurations. This is based on the fact that the vent rules specified in codes do not satisfactorily account either for slippage between air and water or for recirculation relief in vent networks. Both effects probably exist to an appreciable degree in lightly to moderately loaded, branching systems as used in multistory buildings of low to moderate height, and substantial recirculation relief undoubtedly occurs in high-rise systems utilizing individual venting, wet venting, or circuit-and-loop venting.

Among additional investigations that could provide better definition of the functional performance of reduced-size venting, and that could establish a broader base for the application of reducedsize venting to various designs under the many possible service conditions are the following:

1. Experimentation with reduced-size venting with greater numbers of vent-system elements, greater heights, and greater fixture-unit-loads than those represented in the research reported herein. This would be helpful both in perfecting and in expanding table 12 to make it applicable to a wider range of systems.

2. Determination of the dynamic relationships between peak air demand rate, vent pressure, and trap-seal retention over a wider range of pipe diameter, fall distance, fitting shape, pipe roughness, load distribution, etc., than was possible in the study reported here.

3. Development of a rational method [9] for sizing of vent headers and manifold vent terminals, and the improvement of methods for selection of representative hydraulic loads for laboratory tests.

4. Field verification of performance predicted from laboratory tests. This type of feedfback from one or more systems previously tested in the laboratory would serve to confirm and/or improve criteria such as table 12, and to improve test methodology so as to provide suitable agreement between the performance in the laboratory and in the field.

5. Development of representative performance data over a wider range of conditions, concerning possible hydraulic and pneumatic effects of solids and detergents, for comparison with similar data with clean-water loads developed in the study described herein. Investigation of the relative effectiveness of various methods for controlling the effects of detergents. In the long run, trends in the detergent industry appear to be headed toward reduced sudsing and this should be encouraged.

6. Development of representative performance data for vent reservoirs, vacuum relief valves, and unvented vertical sections of soil and waste pipes, all of which received only limited attention within the scope of the component tests referred to herein.

7. Development of appropriate environmental data concerning the magnitude of pressures within sanitary DWV systems that might be attributable to effects of wind pressures or of pressures generated within public sewers or individual sewage-disposal systems.

8. Development of appropriate data concerning the likelihood of frost closure of vents in different geographical locations of the United States. The development of a "frost closure map" or similar guide from official weather records could remove some of the uncertainty in establishing realistic criteria for sizing vent terminals in cold climates.

[9] The empirical sizing methods currently used in experimentation on the performance of DWV systems with RSV and in sizing vent headers in generally accepted practice need verification and improvement through field measurements on systems in service.

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## 7. Appendix

### 7.1. Definitions

For the purposes of this paper, a number of terms are defined in the context of the work reported. In general, the definitions are in accordance with the model plumbing codes, but where necessary to facilitate comprehension, new terms have been defined and some standard definitions have been modified.

Active fixture—A fixture that is discharging for the purpose of creating or contributing to a hydraulic test load, or that is discharging under service conditions.

Air demand—The quantity of air (usually expressed as a volume- or mass-rate) required to be moved through a vent in response to pneumatic pressure differentials created by the movement of water from fixtures discharging into branch assemblies and drainage stacks.

Back vent—A back vent is a branch vent installed primarily for the purpose of protecting fixture traps from self-siphonage.

Blind flange—A blind flange is a cover plate bolted or otherwise fastened across a pipe flange to seal the pipe.

Blow-back—Is the ejection of suds, air, or other gases through the trap seal to the room side of a trap as a result of excessive pneumatic, hydrostatic, or hydrodynamic pressure on the drain side of the trap.

Branch—Is any part of the piping system other than a main, riser, or stack.

Branch vent—Is any vent pipe connecting from a branch of the drainage system to the vent stack.

Building (house) drain, sanitary—The sanitary building or house drain is that part of the lowest horizontal piping of a sanitary building drainage system which receives the discharge from soil, waste, and drainage pipes within the walls or footings of any building and conveys the discharge to the sanitary building sewer.

Code—The word code, as related to plumbing work, usually means an ordinance, with any subsequent amendment thereto, or any emergency rules or regulations which a city or a governing body may adopt to control the plumbing work within its jurisdiction.

Combination wye-and-eighth bend—Is a fitting which was originally made in cast iron to provide the features of two separate fittings, a 45° wye-branch and a 45° bend which together accomplish a 90° change in direction. In some of the newer materials used for drainage fittings, the wye-and-the-eighth bend are assembled into one fitting by the user.

Common vent—Is a vent connecting at the junction of two fixture drains and serving as a vent for both fixtures.

Cross flow—Is the movement of waste water from the trap of an operating (active) fixture to the trap of a nonoperating (idle) fixture. [Could also be defined to cover movement from active to idle branch drain, etc.].

Diameter—Unless specifically stated, the term diameter means the nominal diameter as designated commercially.

Dip of trap—The dip of the trap is so located as to be the highest point on the internal wall of the trap at the cross section where the bend (inverted siphon) of the trap is at its lowest part.

Drain—Is any pipe which carries waste water or water-borne wastes in a building drainage system.

Dual vent—(sometimes called a unit vent) Is a group vent connecting at the junction of two fixture branches and serving as a back vent for both fixtures.

DWV system—The drain-waste-vent system, includes all the sanitary drainage and vent piping inside the building or relevant portion thereof, and includes the building drain to its point of connection with the building sewer.

Fixture drain (also called trap arm)—Is the drain from the trap of a fixture to the junction of that drain with any other drain pipe.

Fixture load—The fixture load is the term used to indicate the types and sum total of fixtures connected to a plumbing system or portion thereof.

Fixture unit (drainage)—The term fixture unit identifies a measure of the probable discharge into the drainage system by various types of plumbing fixtures. The fixture unit value for a particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation, and on the average time between successive operations during peak use periods.

Fixture unit load—Is the sum of the numerical values of the fixture-unit ratings for all the fixtures connected to a plumbing system or portion thereof.

Fixtures or appliances, plumbing—Plumbing fixtures or appliances are installed receptacles or devices which are supplied with water, or which receive liquid and/or discharge liquids, or liquid-borne wastes, either directly or indirectly into the drainage system.

Flood-level rim—Is the top edge of a receptacle or fixture bowl from which water can overflow.

Frost closure—Is the partial or complete closure of a roof vent in cold weather by the formation of a layer of frost on the inner surface of the vent.

Group vent—Is a branch vent that performs its functions for two or more traps.

Group venting—is the arrangement of the drainage piping such that a single vent may serve more than one fixture. Wet venting is one form of group venting.

Horizontal branch—A horizontal branch is a drain pipe extending laterally from a soil or waste stack or building drain with or without vertical sections or branches, which receives the discharge from one or more fixture drains and conducts it to the soil or waste stack or to the building drain.

Idle fixture—A fixture that is not discharging during the imposition of a hydraulic test load by active fixtures, or by natural use of the system in service.

Individual vent—Is a pipe installed to vent a single fixture trap and so connected with the vent system or with the open air that free movement of air is possible at all times.

Induced siphonage—Is the process whereby a reduction in the surface level of a trap seal of a fixture is caused by the discharge of other fixtures on the system, such discharge resulting in transient local pressure fluctuations that siphon or otherwise remove water from the trap.

Main vent—Is the principal artery of the venting system to which vent branches may be connected.

Manifold—Is a pipe fitting with several outlets for connecting three or more pipes.

Nominal size—Is the approximate size of the pipe or tube. The actual size within tolerances is defined by standards established for various types of pipe or tube.

Performance criteria—Performance criteria are the attributes or characteristics of a (plumbing) system, or element of the system, which are measured or evaluated to determine on some quantitative scale whether the performance requirements (health and safety, comfort, convenience, efficiency, durability, etc.) have been met.

Piezometer—A piezometer is a device for the measurement of pressure in pipes or conduits consisting of a vertical transparent tube which is connected at its lower end to a piezometer orifice in the wall of the pipe or conduit and is open to atmosphere at its upper end. The height to which fluid rises in the transparent tube is a measure of the head or pressure in the pipe or conduit.

Piezometer Orifice—A piezometer orifice is a small hole through the wall of a pipe or conduit drilled at a 90° angle to the wall and carefully finished at the inner edge of the hole.

P-trap—The P-trap, resembling an inverted siphon, is one of several designs of devices used in drains to provide a water seal.

Reach—A reach is one of the continuous sections of a pipe, e.g., a drain pipe located between inlets or between inlets and outlets.

Recirculation—Recirculation in a DWV system is the flow of air within the network comprised of interconnected vent piping, to meet the demand for air in critical areas inside the system as water is discharged from the fixtures.

Reduced-size venting—A type of venting which utilizes dry vent sizes smaller than permitted by plumbing codes. Such reduced-size vents are limited to locations not lower than 6 in above effective flood level for the fixtures involved.

Roughing-in—Is a term indicating the installation of all parts of the plumbing system which can be completed prior to the installation of the plumbing fixtures. This includes drainage, water supply, vent piping and the necessary fixture backing/supports.

Run (test)—A complete hydraulic event, beginning with the discharge of selected fixtures and ending when the water so discharged has passed through the DWV system.

Self-siphonage—Reduction in trap seal of a fixture after completion of the fixture discharge, caused solely by the discharge of that fixture.

Service Weight (soil pipe)—The designation of a weight or thickness of cast-iron soil pipe. Soil pipe is designated extra-heavy (XH) and service (SV). Class (SV) has a wall thickness of approx 70 percent that of class (XH).

Slab-on-grade (slab on ground)—Is a term used to identify a concrete floor poured on the ground at grade level when necessary precautions have been taken regarding ground water or unstable soils.

Slippage—The term used here to indicate the degree to which the mean velocity of the air is less than the mean velocity of the water at a particular cross section in a soil or waste stack in which falling water carries air with it.

Slope (grade)—Is the degree or extent of deviation from the horizontal, usually expressed in in/ft for plumbing drains.

Stack—Is the vertical main of a system of soil, waste or vent piping.

Stack vent—(sometimes called a waste vent or soil vent) Is the extension of a soil or waste stack above the highest horizontal drain connected to the stack.

Stack venting—Is a method of venting a fixture through the soil and waste stacks, without the use of individual, branch, or relief vents.

Trap—A fitting or device constructed so as to provide, when properly vented, a water seal for protection against the emission of noxious or explosive sewer gases, without significantly retarding the flow of sewage or waste water through it.

Trap arm—Is another name for fixture drain.

Trap seal—Is the vertical distance between the trap weir and the dip of the trap.

Trap-seal retention—Is that depth of water remaining in the trap after the trap has been affected by passage of fluid through the trap or by action of suction or back-pressure in the DWV system.

Trap weir (crown weir)—Is the lowest point in the vertical cross-section of the horizontal waterway at the exit of the trap.

Vent—Is a pipe installed to provide a flow of air to or from a drainage system or element thereof so as to provide protection of trap seals from siphonage and back pressure.

Vent stack—A vertical vent pipe extending through one or more stories, installed to provide circulation of air between different elements of the DWV system. Usually, the vent stack is the vertical main of the vent system, to which branch vents are connected.

Vent stub—Is the length of code-size vent that extends at least six inches above the flood-level rim of the fixture, as employed in the research on reduced-size venting.

Vent terminal—Is that portion of the vent piping extended outside the building and open to the atmosphere.

Vertical pipe (soil, vent, or waste)—Is any pipe which is installed in a vertical position or at an angle with the vertical of not more than 45 degrees.

Waste stack—Is the vertical main of that portion of a drainage system which carries no urine or feces. its stack vent may extend independently through the roof or it may connect to the stack vent of the soil stack.

Wet Venting—is the arrangement of the drainage piping such that the venting of some fixtures is provided by pipes that also serve as drains for other fixtures.

## 7.2. Units of Measure and SI Conversion Factors

The results of the investigation described herein are reported primarily in conventional U.S. units, for two reasons: first, most of the instrumentation used was calibrated and graduated in conventional units; second, the results of this research are directed to those groups who ordinarily use conventional units.

However, in recognition of the increasing importance of international standards in foreign commerce and of international technical committee activity in plumbing technology, it is recommended that those who utilize the results of this work assume the responsibility for appropriate conversion to International Standard (SI) units, recognized by the USA in 1960 as a signatory to the General Conference of Weights

and Measures which gave official status to the metric SI system of units. For this purpose, the following conversion factors are given applicable to the conventional U.S. units used in this paper:

*Force*

1 pound (lb) = 4.448 newtons (N)

*Length*

1 inch (in) = 0.0254* meter (m), or 25.4* millimeters (mm)

1 foot (ft) = 0.3048* meter (m), or 30.48* centimeters (cm)

*Mass*

1 pound [avoirdupois] (lb) = 4.536 kilograms (kg)

*Temperature*

Degrees Celsius (°C) converts to (°C + 273.15)* degrees Kelvin (°K or K)

Degrees Fahrenheit (°F) converts to 1.8 (°F — 32) degrees Celsius (°C)

also converts to 1.8 (°F — 459.67) degrees Kelvin (°K or K)

*Time*

1 minute [mean solar] = 60.0* seconds (s)

*Area*

1 $in^2$ = 6.4516* x $10^{-4}$ $meter^2$ ($m^2$), or 6.5416* $centimeter^2$ ($cm^2$)

*Volume*

1 gallon [U.S. liquid] = 3.785 liters (l) = 3.785 x $10^{-3}$ $meters^3$ ($m^3$)

*Volume/Time*

1 gallon [U.S. liquid] per minute (gpm) = 6.309 x $10^{-2}$ liters per second (lps)

also = 3.785 liters per minute (lpm)

*Velocity*

1 foot per second (fps) = 3.048* x $10^{-1}$ meters per second (m/s)

1 foot per minute (fpm) = 5.080* x $10^{-3}$ meters per second (m/s)

*Pressure*

1 psi = 6895 newtons per $meter^2$ ($N/m^2$)

1 inch of water column [at 39.2°F] = 249.1 newtons per $meter^2$ ($N/m^2$)

1 inch of water column [at 60°F] = 248.8 newtons per $meter^2$ ($N/m^2$)

### 7.3. Discussion of Field Tests Conducted by the NAHB Research Foundation, Inc.

A discussion of field tests conducted for the National Association of Home Builders (NAHB) is presented here for the following reasons:

(a) The field program described represents the only known planned study to verify the performance of reduced-size venting as designed on the basis of the NBS laboratory findings and as installed in actual houses.

(b) The work provides the basis for a comparison of the vent sizes used for the service installations with the minimum sizes indicated by table 12 of this paper.

(c) The results point out the importance of systematic test procedures and accurate measurement techniques, and demonstrate the need for field data on (i) plumbing loads to provide an improved basis for selection of laboratory test loads, and on (ii) hydraulic performance with service loads to provide final confirmation of the adequacy of an innovative design.

The NAHB Research Foundation (NAHB RF), a subsidiary of the National Association of Home Builders, cosponsor of the laboratory work described in section 1 through 6 of this publication conducted field tests on DWV systems with reduced-size vents installed in test houses located in the following geographical areas:

1. Camden, New Jersey (two houses). Both houses were one-story ranch style, slab-on-grade construction, with 3 bedrooms and 2 bathrooms each.

2. Muncie, Indiana (one house). This house was one-story ranch style, crawl-space construction, with 3 bedrooms and 2 bathrooms.

3. Fremont, California (one house). This house was a one-story ranch style, crawl-space construction, with 3 bedrooms and 2 bathrooms.

4. Fairfax, Virginia (one house). This house was a bilevel style, having two branch intervals of plumbing, with 3 bedrooms and 2 bathrooms.

In addition, the NAHB Research Foundation stated that a builder in central Illinois has reported observations on seven units employing reduced-size venting in his own program. The houses were described as follows:

1. One-story, ranch style, basement construction, with 2 bathrooms (one house).

2. Split-level style with 3 bathrooms (two houses)

3. Split-foyer style with 3 bathrooms (three houses).

4. Two-story, three family apartment building over basement, with one bathroom in each living unit (three living units).

The principal aspects of the venting designs, of the tests, and of the findings, that are of interest herein are summarized as follows:

1. The systems in the NAHB RF program were selected by the NAHB RF staff as modifications of designs acceptable under codes in the sense that the code-approved DWV configurations were not changed, but the conventional sizes of some of the dry vents were reduced.

2. The NAHB RF utilized the early reports of the NBS on the laboratory study of RSV that had been conducted by NBS, as an aid to down-sizing the conventional vents of selected conventional DWV designs. In several instances staff of the NAHB RF consulted with staff of the NBS in reviewing plans for the modified designs, and in planning site tests.

3. NBS staff did not conduct or direct the conduct of site tests, nor prepare the test procedures actually used by test personnel. An NBS staff member observed the conduct of the tests of the system in the Muncie, Indiana house that were made before occupancy.

4. All of the systems are shown as installed with vents reduced in size to a substantial degree below the sizes of those ordinarily permitted by codes. For details of the DWV piping configurations; pipe sizes;

and fixture types, numbers, and locations the reader is referred to NAHB RF Report LR 210–17, September 1971 [2].

5. The NAHB RF reported that before-occupancy tests in five houses, and after-occupancy tests in two of the houses made after periods ranging from 15 to 24 months, showed that trap-seal reductions did not exceed one inch or 50 percent of the initial full trap seal in any test. The builder in Illinois who conducted his own study in seven units is credited with reporting "satisfactory performance."

The authors of the present paper have reviewed the four sets of plans (Camden, Muncie, Fremont, Fairfax) shown in NAHB RF Report LR210–17. This review shows that a number of the vent pipes were sized one to two pipe sizes smaller than might have been obtained through the use of the sizing table shown although the magnitude of the discrepancy may depend to some extent on the interpretations made of the table when applied to the particular DWV configurations. It should be realized that the table was not completed, even in tentative form, when most of the test houses were designed. Thus it is not surprising that not all the sizes actually used can be obtained from the table.

The numbers of fixtures discharged together to create the test loads generally seem to be as great as or greater than would be obtained by the use of table 1A of BSS 41 [12]; however, a review of the rationality of the particular choices used was not presented in the report, nor has one been attempted by the authors of the present paper.

Trap-seal reductions reported exceeded 1 in only for the two-story system (Fairfax, Virginia), and that occurred only after multiple applications of the test loads without replenishing the idle trap seals. The data show that even in these cases at least 50 percent of the trap-seal depths were retained after four to six successive applications of the loads.

The report does not describe or discuss the methods of measurement used nor does it give any calibration data for the discharge characteristics of the fixtures. In some of the tests, measurements evidently could not be made on the bathtub traps, nor on traps connected to food waste disposal units. A detailed presentation and discussion of these items would have improved the report.

With reference to the independent tests reported by the Illinois builder (but for which measurements are not shown) the vent-size reductions seem rather extreme in view of the data shown for the houses tested by the NAHB RF. A further concern relates to the termination of the vents in the attic space. This might contribute to excessive moisture and the accumulation of foul and possibly hazardous gases within the structure.

It is unfortunate that it was not possible for the field program to provide for measurements of performance with natural loading patterns, i.e. "people" loadings. The field tests reported utilized "heavy" loads chosen from a consideration of the state of the art for DWV load-testing, but nonetheless, loads chosen by test engineers and applied by test engineers—not by the building occupants themselves as a natural part of their daily living patterns. Until suitable updated data on load patterns generally are obtained, purposeful evaluations of innovative plumbing systems should provide for some measurements of the significant performance parameters in field trials with natural loadings, after laboratory tests have first shown the system(s) to offer strong promise.

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A laboratory study of one-story and split-level experimental drainage systems where the vents in some cases were varied from one to six pipe-sizes smaller than those presently specified by codes showed satisfactory hydraulic and pneumatic performance under various loading conditions. The research was originally sponsored by the National Association of Home Builders and the National Bureau of Standards and more recently by a program of the Department of Defense through the Tri-Services Investigational Committee on Building Materials. This paper presents criteria recommended for the design and evaluation of systems using reduced-sized vents and a sizing table for one- and two-story systems. The laboratory work also contributed to the development of analytical and test procedures needed for evaluating the application of reduced-size venting to a broad range of innovative drain-waste-vent designs for buildings of any height.

This work indicates that, in some circumstances, reduced-size venting might be a good alternative to other types of drainage systems for multi-story buildings which use either conventional or innovative venting concepts. Because this study involved only a limited number of drainage system designs, it is recommended that ongoing field and laboratory studies be explored if code changes are contemplated to permit the use of smaller vents.



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